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Melting Iron In The Cupola

Modern Practice in the Construction,
Maintenance and Operation of
The Cupola in the Gray Iron Foundry

By

J. E. HURST

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1929

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PREFACE

FOR information regarding the iron foundry cupola, its development, construction and operation the foundryman has had to rely on the sections dealing with this subject in the larger works on iron founding and metallurgy and the various articles scattered throughout the technical press. The importance of the subject and its many aspects are ample justification for dealing with it in a separate volume. It is the author's desire that foundrymen and all those connected with and interested in, the foundry industry shall find this presentation of the subject of value.

The author gratefully acknowledges the assistance by way of information and illustrations rendered by Mr. J. G. Pearce and the British Cast Iron Research Association, Mr. G. C. Lloyd and the Iron and Steel Institute, Mr. V. C. Faulkner of *The Foundry Trade Journal*, Mr. V. Delport of THE FOUNDRY, Mr. P. H. Wilson of The Stanton Iron Works Co., Ltd., England, Mr. A. N. McQuistan of Messrs. Cochrane & Co., Ltd., Middlesbrough, England, Mr. D. H. Wood of The Constructional Engineering Co., Ltd., Mr. W. Rawlinson of Messrs. J W. Jackman & Co., Ltd., Mr. W. B. Parker and Messrs. The British Thomson Houston Co., Ltd., England, Mr. John Cameron, Mr. John Shaw, England, and Mr. Robert Eppenberger, Paris.

The various manufacturers of cupola plant and auxiliaries both in Great Britain and America have been most liberal in placing information and illustrations at the author's disposal. The author is deeply indebted to them.

In preparing this work the author has consulted freely the available text books and has drawn information from the many

investigations which have been published in technical literature. In acknowledging his indebtedness to all these writers and investigators it is fitting to make special mention of the treatise on foundry cupolas by the late Edward Kirk. Although out of print this work is still known and by no means forgotten.

Finally the author desires to convey his thanks to the Penton Publishing Co., Cleveland, for including this book in their admirable series of technical books. The book has been edited by their staff of *The Foundry*.

October 1, 1929

J. E. HURST
Burndale, Housely, Chapeltown,
near Sheffield, England.

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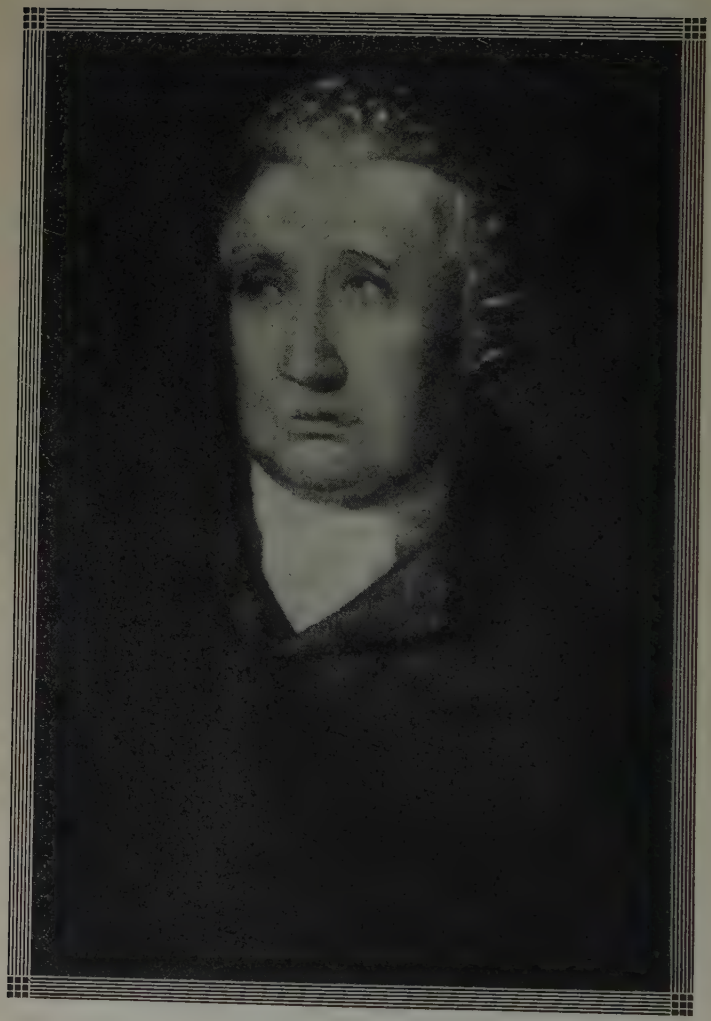


JOHN WILKINSON

CHAPTER I

Historical

Definition of the iron foundry cupola—Shaft furnaces—Origin of the word cupola—Cupola construction of blast furnace—Wilkinson's patent—Early history of iron founding—Wilkinson as inventor of cupola—Traveling tinkers—The cupola in China—Development in the nineteenth century—Spencer's receiver—William and Jonathan Ireland—George Hinton—The Woodwards—The Herbertz cupola—Hot blast cupolas—Tuyere arrangement.

THE cupola furnace is practically universal in its application to the melting of cast iron for foundry purposes. It may be defined as a shaft furnace, utilizing solid fuel, in which the heat is generated by the injection of an air blast into the incandescent fuel contained in the shaft. The heat thus generated is absorbed by the material to be melted, which is contained along with the fuel in the shaft. The molten material is collected in a hearth, formed at the bottom of the shaft, whence it may be withdrawn as desired.

To any historical student acquainted with metallurgical processes, it is quite evident that this furnace is identical, in type and character, with the shaft furnace, the earliest form of furnace known, dating back to the dawn of metallurgical history. The shaft furnace was not even confined to iron smelting. In a furnace of this type, man first reduced metals from their ores. Even today, the shaft furnaces used in copper smelting are referred to as cupolas. Furthermore, apart from the size and magnitude of the auxiliary plant, no real difference exists between the cupola and the modern blast furnace.

Any study of the history of the iron-foundry cupola is not concerned with the origin of the type of furnace, but rather with the origin of its application as the foundry melting unit. In other words, the modern iron-foundry cupola is differentiated from other shaft furnaces by the fact that it is solely confined to the remelting of iron for foundry purposes. The modern iron blast furnace is confined to the smelting iron from ores.

The name cupola, as applied to furnaces, apart from its

use in the copper industry appears to be confined today to the iron-foundry melting unit. It is interesting to note, in passing, that in the modern European languages, as in our own, the cupola is differentiated from the blast furnace by the use of a separate name. Moreover, these names closely resemble our own appellation. Equivalents of the English terms *Cupola* and *Blast furnace* in various European languages follow in tabular form:

Language	Iron-foundry	
English	Cupola	Blast furnace
French	Cubilot	Haut-fourneau
German	Kupelofen	Hoch-ofen
Spanish	Cubilote	Alto-horno
Italian	Cubilotto	Alto-forno

The word cupola appears to be derived from the Latin root *Cupula* which means a small cask, the diminutive of the noun *Cupa* meaning a tub. Apart from its application to foundry furnaces, the word cupola in the English language, has also come to possess a definite architectural meaning, in which it is used to define a spherical or spheroidal roof or covering to a building. It is now difficult to perceive any connection between the two applications of the original Latin root word.

According to Moldenke, the name cupola, as applied to a metallurgical unit, appears to have originated in Germany. In a writing, dated 1454, the extended shaft or chimney of blast furnaces is referred to as Kuppel. Moldenke is of the opinion that this is the first mention, in the history of the shaft furnace, of a word resembling our word cupola. Iron castings were not made from remelted metal until some 250 years later, which seems to indicate that the term cupola, as applied to shaft furnaces, was in existence long before its meaning was narrowed down to present-day limits.

Earliest reference to the cupola furnace in the British *Patent Journals*, is dated 1635. In that year, a patent was granted to one Thornese Francke for "altering the formes of melting furnaces and bringing the wynd into the said furnaces, which shall make the fyers burn with as much violence as any

blast whatsoever." There are no drawings or illustrations extant with this patent and it is impossible to conjecture what form the subject of the invention took. From the date of this patent it is apparent that its application was confined to smelting ores. This constitutes additional evidence and it is almost certain that the restriction of the word cupola to furnaces for remelting iron for foundry purposes is of a much later date than its application to shaft furnaces in general.

Development of the shaft furnace in general from the early shaft like hearths used for smelting ores, and typified by the Hindu *wootz* furnaces, still to be found in the remoter parts of India, is familiar to most students of metallurgy. Apart from developments in the application of mechanical operating features, the outstanding development has been one of steady increase in height. In Europe, the equivalent of the Hindu *wootz* furnace, was the more or less shallow hearth type of furnace known as the Catalan hearth. This developed by increase in height through the stage of the *osmund,* high hearth type, to the *stuckofen* or *blauofen* in which the shaft was further extended in the form of two truncated conical shafts placed end on end, a form of construction containing the first glimpse of the modern blast furnace.

This development in the height of shaft furnaces is commemorated in the modern European words, equivalent to the English word blast furnace: *haut-fourneau* and *hochofen.* Excellent illustrations of the Catalan hearth, the osmund and blauofen furnaces are to be found in most of the older metallurgical textbooks (vide Percy, *Metallurgy of Iron*). This increase in height of shaft furnaces as applied to iron smelting has a special metallurgical significance. Largely it was responsible for the change in character of the product from wrought iron to cast iron.

Although the interior of the shaft in the early blast furnaces was cylindrical or conical, the exterior usually was rectangular in the form of a truncated pyramid. This early type of blast furnace has been in operation in Europe until quite recent times. Rectangular exterior was due to the use of stone as construction material. Considerable expense was avoided in constructing a square exterior instead of dressing the stonework to cylindrical form.

With the adoption of molded fireclay bricks the cylindrical or conical form gradually supervened. In the early stages the furnaces were built to cylindrical form above the boshes and finally the complete cylindrical form was adopted. During this transition stage, the relative merits of the two forms of construction formed the subject of many grave discussions among blast furnace men. Prior to the adoption of complete steel casings, the cylindrical furnaces constructed of brickwork often were banded with wrought iron straps. According to Overman, *The Manufacture of Iron,* the construction embodying the rectangular form up to the boshes and the cylindrical, banded form above was referred to as the cupola form of construction. One of these furnaces was used at the plant of the Great Western Ironworks of Pennsylvania, U. S. A.

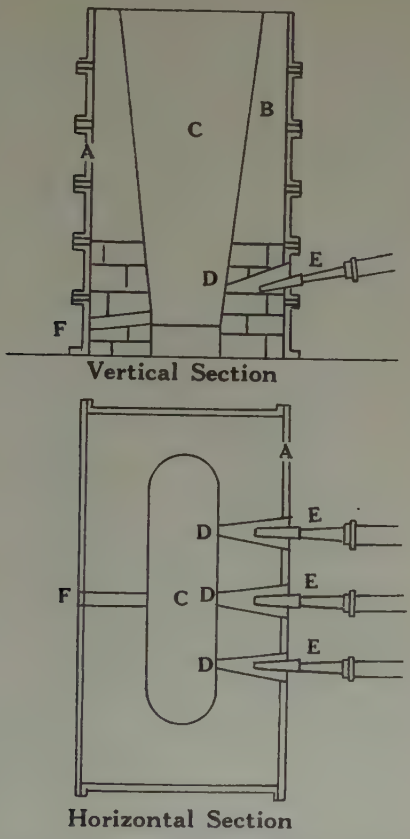
The description, cupola, applied to this form of construction probably was employed owing to the resemblance of the extended cylindrical banded shafts to a cask. Since this form of construction was applied commonly to cylindrical shaft furnaces even before this date, the opinion seems justified that their barrel-like appearance prompted the designation—cupola.

Application of the cupola to iron-founding purposes, as distinct from iron smelting, usually is attributed to John Wilkinson, the early English pioneer of iron founding. This great ironmaster was born in 1728 and died in 1800. In the year 1794 he was granted a patent (No. 1993, dated June 2), for an invention described as "A New Method of Making Cast Metal or Pig Iron from the Ore, for the Purpose of Manufacturing it Into Bar of Any Sort of Malleable Iron."

A reprint of this patent, dated 1856, still is available. The invention briefly is described with the aid of drawings. The drawings are reproduced in Figs. 1, 2, 3 and 4 and the description follows:

"Instead of melting the ore with additions in furnaces 30 feet to 70 feet high, as in the present method, my improvement or invention consists in using a low erection, not exceeding 10 feet high, of a form either circular, oblong, or square, in which any kind of ore or fuel may be smelted, and in which a strong blast is introduced at two or more places called twires, which are varied in number as the nature of the ore and fuel may

require. Any workman in the present method may, from this description, alter his furnace to suit the quality of his materials. A drawing of two or three twires is given as a specimen, which

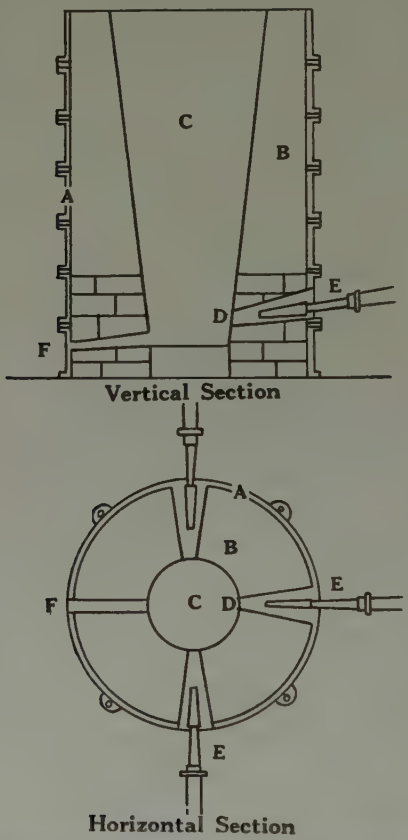


FIGS. 1 AND 2—VERTICAL AND HORIZONTAL SECTIONS RESPECTIVELY, TAKEN FROM THE DRAWING SUBMITTED BY JOHN WILKINSON FOR BRITISH PATENT NO. 1993, JUNE 2, 1794, A DEVICE FOR MELTING IRON

may be altered in height and dimensions with addition of twires as to the workman may appear needful."

The drawings included in the specifications, were accompanied by the following references. *A*, cast-iron plates forming outside of the furnace; *B*, the luteing or inside walls made of sand stone, firebricks or any other materials suitable for the

purpose; *C*, cavity for fuel and the ore to be smelted; *D*, twire hole through which blast is brought to the furnace; *E*, the blowing pipe by which the blast is brought to the furnace; *F*, the



FIGS. 3 AND 4—VERSATILITY OF WILKINSON IS SHOWN IN HIS ORIGINAL SPECIFICATION, WHICH PROVIDES FOR A CIRCULAR FURNACE WITH THREE TUYERES DISPOSED AROUND THE CIRCUMFERENCE IN ADDITION TO THE RECTANGULAR FORM SHOWN IN FIGS. 1 AND 2

tap hole or vent for the metal. The design and construction of this furnace are identical with those of the cupolas used in the early iron foundries, a few of which still remain. While it is more than probable that John Wilkinson or his successors (it will be noted that the patent was granted only six years before

his death) used this type of furnace for remelting iron, it is described as a furnace for smelting ore. In other words, it was intended to be a miniature blast furnace.

Further light on the origin of the cupola as an instrument for remelting iron is gained from a consideration of the development of the iron-founding industry. Few traces of iron castings exist prior to the fourteenth and fifteenth centuries. It is recorded that the Romans were familiar with cast-iron statuary, stated to have been introduced about the year 170 A. D. by the Samian Theodorus. A small Roman statuet, said to be of cast iron, is recorded as having been found in the parish of Battle, Sussex. Moldenke refers to a bridge in Japan embodying cast-iron chains and dating back to about 70 A. D., and F. A. Foster in *The Foundry*, Feb. 15, 1926, states that iron castings have been made in China for at least a thousand years. It is of importance to note that a certain amount of uncertainty exists with regard to many of the early specimens recorded as being of cast iron, and it is frequently doubtful whether sufficient care has been taken to differentiate between the material cast iron and what we now understand to be wrought iron.

From these early times little is found regarding cast iron, until we hear of cannon balls, cast of white iron, obtained from the blast furnace by suitable regulation of the blast, at Menningen in the year 1388. However, the first authentic record of iron castings in England is in connection with the manufacture of cannon, at Buxted, in Sussex, by Ralph Hogge or Hoge, in the year 1543. Hogge was assisted in his work by Peter Baude, a Frenchman, whom he brought over from France, a fact which indicates that iron founding was practiced in that country sometime, at least, prior to this date. Baude subsequently started business on his own account, for it is recorded that his "covenanted servant, John Johnson, excelled his master in the art of casting ordnance, making them cleaner and to better perfection." His son, Thomas Johnson, in and before the year 1595, cast 42 "great pieces of ordnance," each weighing 6000 pounds, for the Earl of Cumberland.

The British export trade in heavy ordnance must have at-

tained considerable proportions by 1572, for in that year, the merchants of London petitioned Queen Elizabeth to revoke the export license which had been granted by the Lord High Admiral to Sir Thomas Leighton. This was done by proclamation, but, in spite of this, Sussex cannon were surreptitiously exported, and it was maintained that Spain armed her fleet with cannon exported from England. For practically a century and a half the use of cast iron was confined to the production of ordnance and in all cases the metal was obtained direct from the ore by smelting in the blast furnace, using charcoal as fuel.

In the year 1709, Abraham Darby, a native of Birmingham, while in charge of a brass foundry in Bristol, and, with the assistance of a Welsh youth, John Thomas, discovered a method of making cast-iron cooking pots. The secret of their process was supposed to have been maintained by them for many years, and, even now, the nature of that secret still remains uncertain. Dr. Percy infers that their success lay in the method of molding, the nature of the sand used, and the method of venting adopted. However, it is probable that the iron used by them was pig iron, remelted in crucibles. Rapid extension of the iron founding industry dates from this time.

The use of coal as a substitute for charcoal had been demonstrated some 50 years previous by Dud Dudley, who died in 1689, 25 years before the advent of Darby. The quieter state of the country, after the civil wars and the disturbances following the Restoration, gave an added impetus to the industry.

Life activities of John Wilkinson are illustrative of the rapid development of the iron-founding industry during this period. Born in 1728, he worked with his father at an iron furnace at Backbarrow, near Ulverston, Lancashire, and was afterward in partnership with his brother and father. It is related in connection with this establishment that John's father carried molten iron, a ladleful at a time, across a road to the small foundry, and cast smoothing irons.

John erected an iron furnace at Wilson House, Cartmel, for smelting the local ore of the Furness district. From this starting point, the two brothers erected iron forges at Bersham,

near Chester; Bradley, Staffs; Willey, near Rugby; Brymbo, Denbigh; Merthyr Tydvil, and other places. At Bilston, in Staffordshire, John constructed the first blast furnace in this area and utilized the coal of the district in place of charcoal.

Here he made the first iron boat to carry fuel along his canal to the furnaces. In a letter dated Oct. 20, 1787, from his Bradley Ironworks, he wrote, "There have been two iron boats launched in my service since September. * * * My clerk at Broseley advises me that she swims remarkably light, and exceeds even my own expectations."

His activities extended to assisting Boulton and Watt in the application of the steam engine for blowing purposes. He also spent considerable time abroad in France, Belgium and Selesia. At Le Creusot in France, he exploited his method of boring cast-iron cannons, and to this day, the cupola is frequently referred to in France as the *Four Wilkinson,* that is the Wilkinson furnace. Some doubt exists as to whether it was John or his brother William who was employed at Le Creusot. A pamphlet issued by the firm of Schneider at Le Creusot some years ago, stated that they "employed the English engineer William Wilkinson, the inventor of the cupola, to put his system into operation at the works."

John erected the first iron bridge at Coalbrookdale, Shropshire, and his many interests included the coking of coal, coal and tar distillation, gas making, and hot blast for furnaces. So thoroughly was Wilkinson imbued with the merits and utility of cast iron, that he made a cast iron pulpit, also cast iron coffins for any who wanted them. He was buried in a cast iron coffin. A cast iron obelisk of his own design, and still in existence, was erected to his memory in the parish of Lindale. Activities of this truly remarkable man serve to illustrate the rapid extension of the iron trade during the 18th century, and it is a fitting tribute to his memory that his portrait should receive prominence in any discussion of cupola practice.

From Wilkinson's general methods it is apparent that the foundries adjoined the blast furnaces, and the molten metal was produced direct from ore smelted in these furnaces. From Wil-

kinson's patent we may infer that he felt the need for a smaller unit, which would be of greater flexibility in meeting the varying needs of his foundry. This patent distinctly states that his furnace was intended for the direct smelting of ore, but one can hardly imagine that so versatile a genius as Wilkinson did not use his furnace to remelt scrap castings, some of which inevitably must have been produced, even in his advanced foundries.

Rapid extension in the use of iron castings for domestic purposes, in the early stages of the development of the cast-iron industry, placed a lucrative business in the hands of traveling tinkers. These itinerants traveled, in districts remote from blast furnaces, equipped with portable cupolas and molding apparatus. Their business was to remelt and recast, or repair broken utensils, on the spot. The cupola as a furnace for remelting cast iron may have originated with these people. In passing, it may be noted that John Bunyan, the tinker probably belonged to this class of artisans.

Reaumur, about 1720, left a description of the itinerant iron founders of the east of France, who traveled from place to place to undertake the repair of cast iron and general domestic utensils. The furnace was a cast iron pot, lined with clay, with an extended shaft built on the edge. Air was introduced by hand or foot operated bellows. Similar furnaces are stated to have been in use in China for at least 1000 years. A complete description of these cupolas has been published on several occasions in *The Foundry,* but there is some uncertainty as to whether the type of furnace described was indeed utilized from the beginning for remelting cast iron.

Outstanding features which emerge from these considerations are that the introduction of the cupola furnace, for the remelting of iron for foundry purposes was more or less gradual and probably originated in this and other countries with the traveling tinkers. Strictly speaking, to describe John Wilkinson as the inventor of the iron-foundry cupola is incorrect. However, broadly speaking, Wilkinson no doubt was the first individual to perceive the necessity for a smaller and more manageable unit than the blast furnace in meeting the demands of organized foundry production.

That his cupola, as described in his patent specification, does not comply with our modern restricted definition of the foundry cupola, and the fact that he probably was preceded by itinerant molders does not constitute sufficient reason for withdrawing from him the title of inventor of the foundry cupola.

After the death of Wilkinson in 1800, and coincident with the rapid industrial development in the early part of the nineteenth century, the foundry cupola received its full share of attention. A brief survey of its development during these years can be traced from the patent records and one cannot help but be struck by the fact that almost every conceivable item in the design likely to improve its efficiency or its adaptability for special purposes, has received attention. The shape of the lining, the shape, position and number of tuyeres, preheated blast, utilization of waste heat, storage of molten metal, desulphurization, all these aspects of cupola design and practice, many of which still figure prominently in the polemics of today, received full measure of attention.

Cast-iron plate construction originated by Wilkinson, was the form adopted by the various iron foundries which rapidly developed throughout England. The internal form was generally cylindrical and lined with good sandstone. These cupolas are still within the membory of many living foundrymen.

Patent No. 5031, dated 1824, in the name of John White (the younger) and Thomas Sowerby is the first patent recorded in the British patent journals, in which direct reference is made to the alternate charging of coke and pig iron. Other patents follow, relating to the design of cupolas operating by natural pressure of the air in place of a blast and by a down draft aided by an exhaust fan.

Utilization of waste heat from the cupola in a separate chamber provided for calcining iron ore was the subject of a patent granted in 1838, and a patent was granted to Richard Stuart Norris in 1851, for a portable cupola, with an arrangement of standards at the top for supporting and preheating the foundry ladles.

A patent of some historical importance, No. 1430, granted

to John Spencer in 1853, covered the invention of an arrangement "by the side of an ordinary cupola for melting cast iron, a second cupola or reservoir so arranged that the contents of the two may be either drawn off separately or both from the same tap hole, when a larger amount of iron is required than one cupola would hold." This is probably the first British patent relating to the use of a receiver. In the same year a patent was granted to William Ireland which contains an early reference to an increase in height of the cupola above the usual. The inside was constructed of a taper form "to prevent the metal sticking or crusting to the sides and provides for hot air to be introduced by a fan or blower."

Provisional protection only was granted to William Clay in 1857, for a cupola in which a draft of air was created by an exhausting apparatus communicating with the upper part of the furnace, which was enclosed. The draft may enter the lower part through tuyeres, and sometimes the apparatus may be arranged to produce a downward draft. This appears to be the forerunner of the steam jet operated cupolas, which appeared later.

Introduction of two rows of tuyeres generally is credited to Jonathan Ireland, apparently the son of William Ireland. This patent was granted in 1858, and covered the application of one or more tuyeres above the ordinary tuyeres, and also the construction of the wind belt within the furnace. A typical illustration of the construction of Ireland's cupola is given in Fig. 5.

George Hinton in 1860, patented a cupola with two or more rows of tuyeres containing 8 tuyeres in each row, the upper row inclined upward, and the bottom row inclined downward. A separate blast belt was provided for each row of tuyeres. In the same year, Hinton was granted a patent for a portable cupola. Provisional protection was granted in 1861 to Hinton and a collaborator for cupolas with a hollow space between the brickwork and the outer casing, through which the blast was arranged to be heated. In the same year Charles Jordan patented a method for the application of the waste gases from the cupola for drying and heating molds.

Another patent of some historical importance is that of George Parry, dated 1861, for melting wrought iron in an ordinary cupola. This patent includes the method of purification of sulphurous coke by using alkalies. Bedson, in 1863, designed and

FIG. 5—IRELAND'S DOUBLE TUYERE CUPOLA

patented a system of water cooled boshes, and in 1865, a patent No. 209 was granted Woodward, relating to steam jet cupolas. The Woodward and the Herbertz steam jet cupolas were used extensively in England. The Herbertz steam jet cupola, shown in Fig. 8, was of somewhat more elaborate construction than the Woodward.

The movable hearth construction clearly shown, was mounted

on four adjusting screws operating in nuts carried on the standards of the cupola. These screws regulated the dimensions of the annular opening between the hearth and the body of the cupola through which the air entered. In some designs, the mov-

FIG. 6—EARLY TYPE HOT BLAST CUPOLA

able hearth and adjustments were mounted on a bogie frame and wheels to facilitate the removal of the hearth and its metal contents from the cupola.

A steam jet supplied with steam at about 80 pounds pressure acting as an injector in the constricted passage illustrated, created an air pressure of from 3 to 4 inches of water gage in the cupola. This was claimed to reduce the melting coke ratio

to 4 or 5 per cent. On a similar cupola in the United States Kirk found that the melting coke consumption was 6 per cent.

Comparison of melting rate of this cupola with present day practice is not possible owing to the omission of the melting zone diameter. The fact that a 52-inch external shell diameter

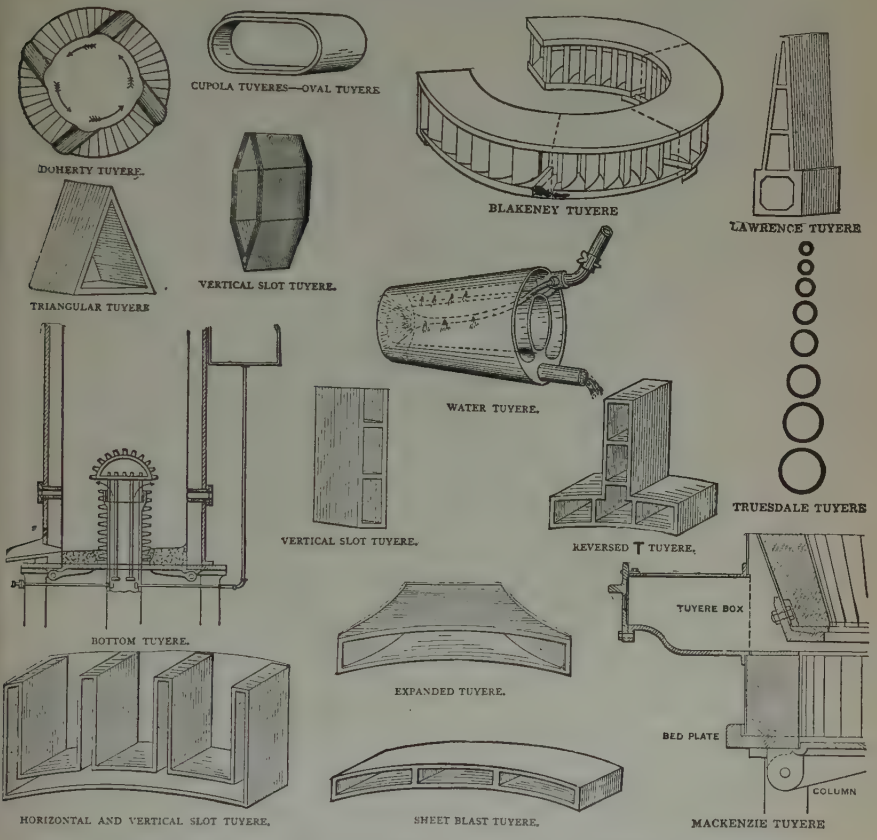


FIG. 7—AT ONE TIME OR ANOTHER PRACTICALLY EVERY CONCEIVABLE SHAPE AND NUMBER OF TUYERES HAVE BEEN TRIED IN THE FOUNDRY CUPOLA IN AN EFFORT TO PROMOTE HIGHER EFFICIENCY

is referred to as the dimension of one of these cupolas having a rated capacity of 2 tons per hour, would appear to indicate that the melting rate of these cupolas was considerably slower than it is today in common practice. A 52-inch shell with a single

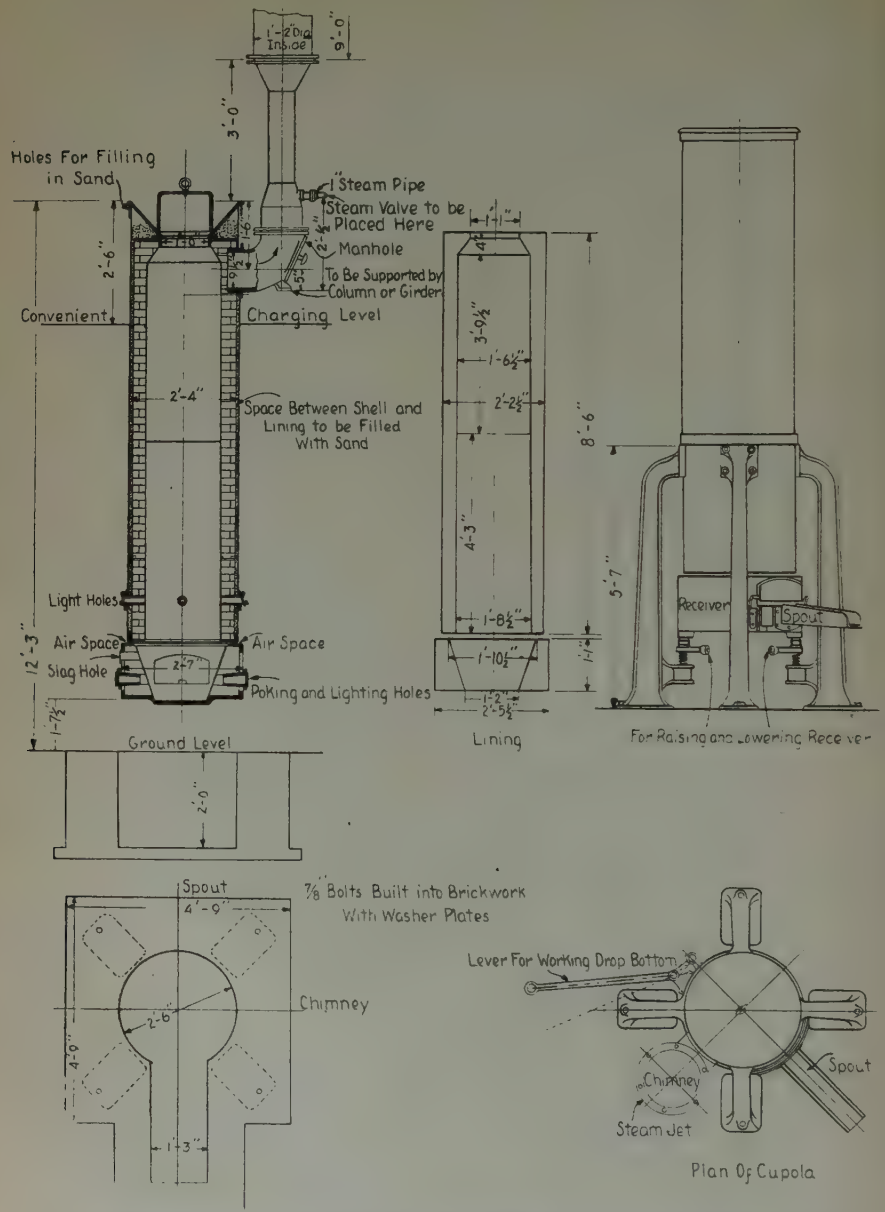


FIG. 8—A STEAM JET SUPPLIED WITH STEAM AT ABOUT 80 POUNDS PRESSURE ACTED AS AN INJECTOR IN THE CONSTRICTED PASSAGE

wall should give an inside diameter of 42 inches and an output of 5 to 7 tons per hour.

In a special design of the Herbertz cupola adopted for melting steel the indrawn air entered the cupola by way of wrought iron pipes embedded in the brickwork and parallel to the vertical axis of the furnace. The pipes were open to the air

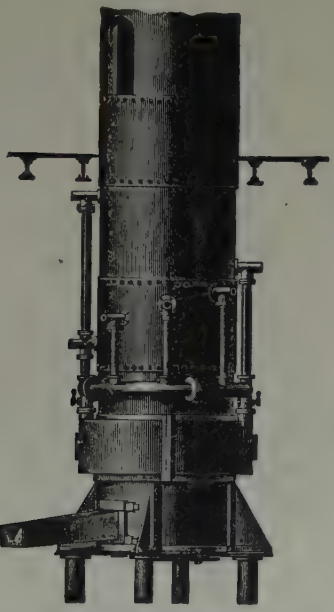


FIG. 9—REGULAR TUYERE BELT IS SUPPLEMENTED BY SEVERAL SMALL PIPES PIERCING THE SHELL AND LINING AT GRADUALLY ASCENDING LEVELS

in the outside shell of the furnace and opened into the shaft of the furnace at a point just above the annular tuyere opening of the standard form, which in this design was stopped off. Claim was made that the indrawn air passing through the tubes embodied in the lining was preheated to a temperature between 275 and 600 degrees Cent.

Preheating the air blast appears to have attracted attention from the earliest times and many proposals have been made with this end in view. Coils of pipe have been suspended in

the upper portion of the furnace stack. Inlet air passing through these coils was preheated by the hot flames and exit gases. An interesting arrangement described by Kirk is illustrated in Fig. 6. Waste gases pass over cast iron pipes erected in a brick chamber leading to a main chimney. This construction is similar to the boiler house economizer and the blast passing to the cupolas is preheated in its passage through the cast iron pipes.

Shape of the internal lining of the cupola above and below the tuyere level has been varied in almost every conceivable manner. Parallel linings, partially expanded linings above the tuyere level, have been used in a variety of forms. Expansion of the well below the tuyere level to take care of large quantities of metal was the basis of the reservoir cupola of William Ireland.

Probably the earliest method of taking care of varying quantities of metal for different requirements was that in which several single tuyeres were arranged vertically above one another on two opposite sides of the early rectangular cupolas. The first tuyere was located approximately 12 to 18 inches above the hearth and the remaining two or three tuyeres were separated by a vertical distance of from 3 to 6 inches. Tuyere nozzles flexibly connected to the blast supply by leather hose usually were connected to the lower level of tuyere openings while the upper openings were stopped with clay. When a larger amount of metal was required the tuyeres were inserted at the higher levels and the lower openings were stopped in a like manner.

Form, construction and arrangement of tuyeres which have been used and adopted at one time or another is legion. Typical examples of the many forms are sufficiently illustrated in Fig. 7 and are taken from Kirk's book maintaining the same nomenclature. Kirk is able to trace the origin of the center-blast tuyere arrangement as far back as 1840 and infers that Ireland used this form of tuyere prior to the introduction of his double tow of tuyeres. A patent was taken out in the United States in 1867 by a Mr. Hibler for a form of center-blast tuyere and reference also is made to a further patented form by Johnson. Thos. D. West made trials with this arrangement in 1893 and other recent attempts have been described in the technical press. Even

with elaborate precautions of water cooling and coating with refractory material it is stated that the possibility of ultimate success is not convincing.

Use of auxiliary tuyeres introducing air at different levels, well up the cylindrical portion of the shaft appears to have been introduced first by D. Y. Stewart of Glasgow. This arrangement was similar in many respects to a later arrangement patented by Greiner and Erpf. The Greiner construction is illustrated in Fig. 9 and the auxiliary tuyeres are arranged spirally up the walls of the stack. This construction is different from that described in the patent in which the auxiliary tuyeres were arranged in rows at different horizontal levels.

CHAPTER II

Construction

Primitive methods and equipment—Standard cupola—The cupola shell—The foundation plate—Columns and hinged bottom doors—Fettling doors—Tapping and slagging spouts—Wind belt and air main—Tuyeres and tuyere arrangement—Spark arresters—Cupolets.

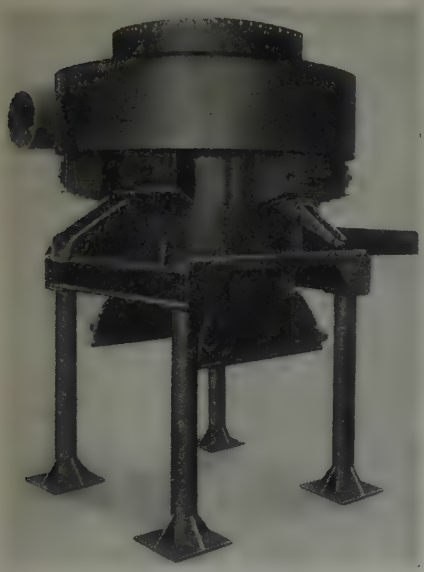
OF ALL the various elaborations in design, proposed with the object of improving efficiency and economy of the cupola, the only one retained to any extent is the double row of tuyeres. The modern standard cupola retains the simplicity of its early progenitors in all essential features and relies entirely for improved efficiency and economy on the dimensional relationship of its various parts. Arrangement of the cupola units and their subsidiaries; charging arrangements, stock yard, arrangements for storing and distribution of the molten metal contribute largely to the overall efficiency of modern cupola plants. The modern foundry cupola plant layout affords an interesting contrast to the older arrangements, cupolas made from open-sand cast iron plates or old boiler shells, the simplest of charging arrangements and molten metal distribution by horse drawn ladle cars. Full credit always must be given to the unerring instinct of the older generations of foundrymen which enabled them to manipulate more or less primitive cupolas and to produce castings not excelled today. The standard of economical operation is not necessarily the same in all foundries. Widely different character of castings demands different qualities in the molten material. Many factors must be taken into consideration in determining successful and economical melting practice.

Shape and proportions of the internal form of the cupola, number of tuyeres, pressure and volume of the air supply, are among the additional factors, independent of the external features of the cupola shell, which influence successful and economical operation of the cupola.

All these factors to a large extent are under the control of the individual foundryman and his advisors. They offer no serious hindrance to cupola builders in constructing standard ranges

of cupolas to take care of various output requirements and embodying their own special forms of construction.

Conditions obtaining in modern foundries demand greater precision and consistency than formerly was the case. They also demand facilities for better and more expeditious manipulation to fit and synchronize with foundry operation constantly develop-



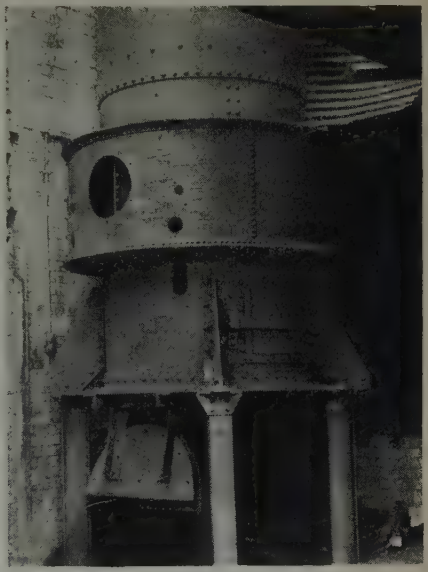


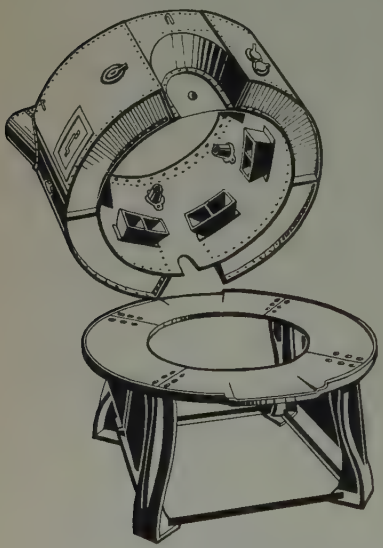
FIG. 10—(LEFT)—WHITING CUPOLA DESIGNED FOR LONG HEATS. FIG. 11—(RIGHT)—BRITISH CUPOLA BY PNEULEC CO., LTD.

ing along lines of greater precision. To meet these conditions, various detailed improvements in design have been introduced into cupolas by the different makers.

Cylindrical construction in riveted mild steel plate is the universally adopted form of modern standard cupola construction. Full detailed capacity ratings and leading overall dimensions of four leading British and American makers are summarized in Tables I and III. These have been selected as typical of the modern range of standard cupolas. Figs. 15 and 16 illustrate the general appearance of cupolas built by the Constructional Engineering Co., Ltd., Birmingham, Eng., and the Whiting Corp.,

Harvey, Ill., respectively. The other two types referred to in the table are manufactured by the Titgen-Eastwood Co., Philadelphia, and Messrs. New Alldays and Onions Ltd., Birmingham, Eng. Figures given in Table II are typical of continental standard cupola construction.

Comparison of dimensions of British and American cupolas



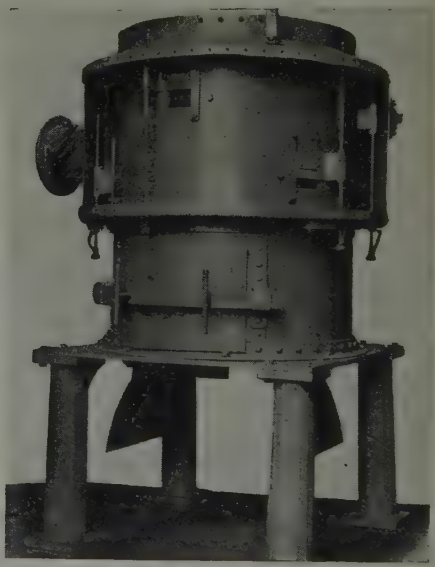


FIG. 12—(LEFT)—BOTTOM FEATURES OF PAXSON-COLLIAU CUPOLA. FIG. 13—(RIGHT)—ENGLISH CUPOLA MADE BY T. DAVIS & SON

shows little essential difference. The rated capacities of the American large size cupolas generally are larger than the British, while the rated capacities of the smaller British types up to about 48 inches diameter generally are somewhat larger than similar American cupolas.

The Whiting Corp. also produces a special series of cupolas built for severe long continuous service. Inside diameters and capacity ratings of these cupolas are identical with those of standard series given in Tables I and III. General arrangement of the body section of these special cupolas is illustrated in Figure 10, showing the special tuyere system in this type of cupola. A detailed description of this system is given later under the dis-

cussion on tuyere arrangement. Other makers also have special designs for heavy duty continuous service cupolas.

The mild steel cupola shell is riveted in sections. Thickness of the plate varies according to the diameter of the shell. Broadly speaking, in cupolas of less than 6 feet diameter the plates are

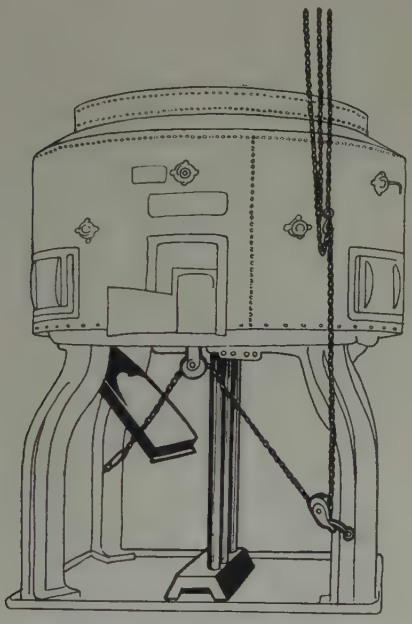
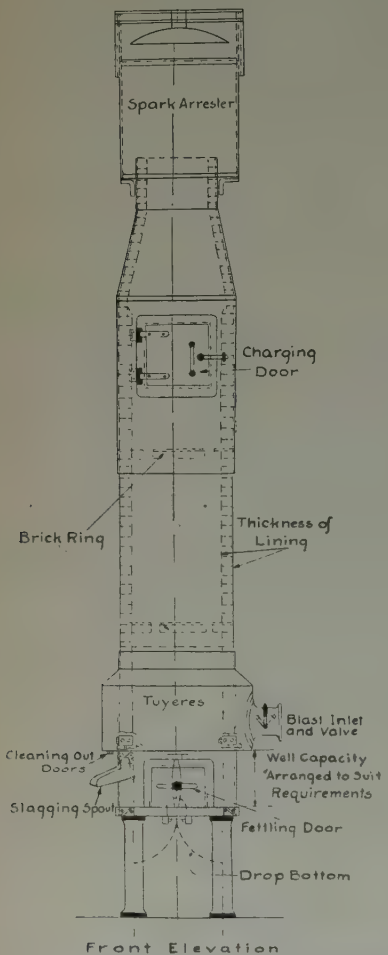


FIG. 14—BOTTOM DOOR HOIST AS APPLIED TO AN AMERICAN CUPOLA

⅜-inch thick. In cupolas above this diameter, ½-inch plates are used. Thick plates are necessary only in the well and melting zone portion of the shell. For the continued portion of the shell up to the charging door and beyond in cupolas of less and greater than 6 feet diameter respectively, ¼-inch and ⅜-inch plates are used by many makers.

Circumferential joints of the plates should be arranged to lap downward to make a weather-proof joint. These joints usually are riveted at 4 to 5 inches pitch, and the vertical seams at 4½ inches pitch. The complete shell commonly is riveted up in two sections to facilitate transport and the two sections are ar-

ranged for bolting together during erection on site. The top of the shell usually is provided with a stiffener angle, riveted inside



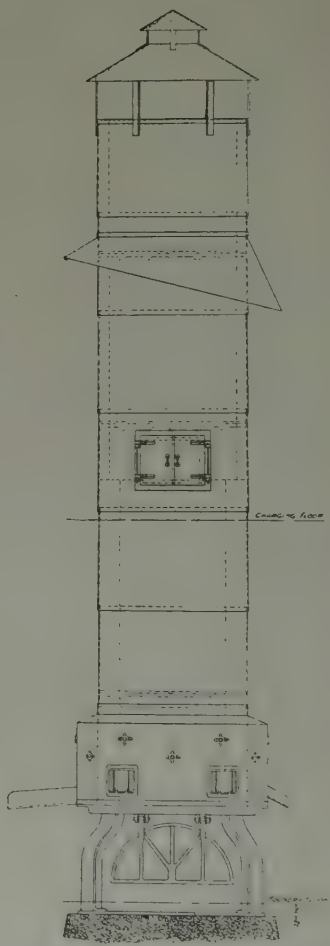


FIG. 15—(LEFT)—SECTIONAL VIEW OF CUPOLA MADE BY THE CONSTRUCTIONAL ENGINEERING CO., BIRMINGHAM, ENG. FIG. 16—(RIGHT)—WHITING CUPOLA EQUIPPED WITH ROOF HOOD AND SPARK ARRESTER

the rim in a manner to prevent excessive percolation of rain between shell and refractory lining.

Suitably placed supports are provided for support of the

refractory lining. These generally take the form of angle iron rings riveted inside the cupola shell. The first ring is placed from 12 to 18 inches above the air chamber so that the bottom portion of the lining may be renewed without removal of the upper portions. Other rings are provided at suitable levels. To eliminate troubles arising from the expansion of these rings, they should be constructed preferably in segments rather than as con-

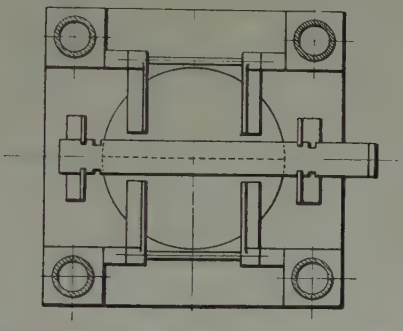


FIG. 17—BOTTOM DOOR LOCKING DEVICE

tinuous rings. In two of the cupolas shown cast iron segments are used for this purpose.

The solid bottom cupola formed by continuing the cylindrical shell down to the floor foundation level, almost entirely has been superseded in modern installations by the drop bottom cupola. Tap hole, slag spout and fettling door are provided at a suitable level and the hearth level is formed by filling the cylindrical shell with firebrick to the tap hole level. The hearth itself is formed in the usual manner of well rammed black sand or ganister. Laborious fettling of solid bottom cupolas will cause any person with a desire to dispute the saving in both personal comfort and time of the operators, to revise his opinion when fettling and dumping the cupola at the end of a day's blow under drop bottom conditions. Without doubt the almost universal adoption of drop bottom cupolas is one of the most outstanding improvements in modern cupola practice.

Cylindrical cupola shell is attached to a foundation plate supported on four columns of suitable height. The foundation plate

is an important feature in cupola construction and considerable attention has been paid to this by different designs. In all cases the foundation plate is provided with a circular hole not less in diameter than the lined diameter of the cupola. This may be closed by two semicircular doors, hinged to swing somewhat out of the vertical when opened. Remains of the day's charge falls from the cupola when the doors are released.

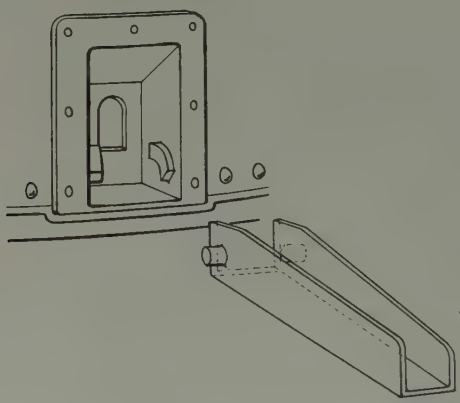


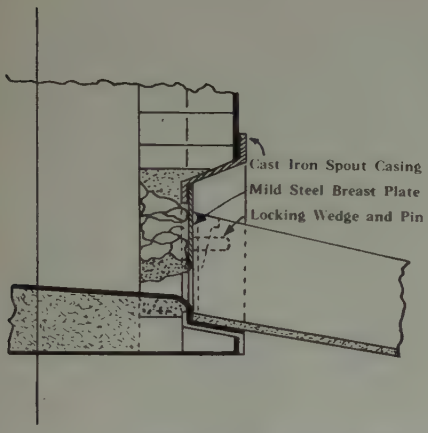
FIG. 18—COMMON METHOD OF HOLDING TAPPING SPOUT IN POSITION

Probably the simplest foundation plate construction is a square mild steel plate of heavy section, not less than ⅞-inch thickness for a 36-inch diameter cupola. A well designed and rigid type embodying the use of a mild steel plate, attached to the shell by annular angle iron ring is illustrated in Fig. 11. Added stiffening is obtained by the use of the mild steel buttresses illustrated. In this case the foundation plate is carried on four columns of rolled steel joist with substantial caps.

Rigidity in the Whiting cupola is obtained by a circular cast iron plate construction, carried on T-section cast columns. Similar cast iron foundation plate construction of the Paxson-Colliau cupola is illustrated in Fig. 12. The wind box is independent of the base plate, made in four extra heavy sections and mounted on a steel bearing plate at the joints carried on the columns. The sectional base plate it is claimed, provides for expansion and con-

traction and therefore will not crack and cause expensive repairs. The Whiting special cupola illustrated in Fig. 10, rests on a foundation plate of heavy structural steel, carried on rolled steel girders, mounted on wrought steel columns filled with concrete.

Opinion probably is divided evenly on the relative merits of steel or cast iron supporting columns and bottom doors. Danger



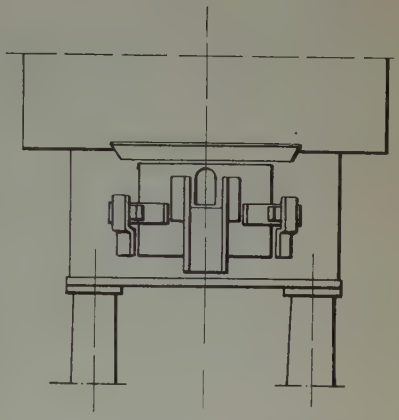
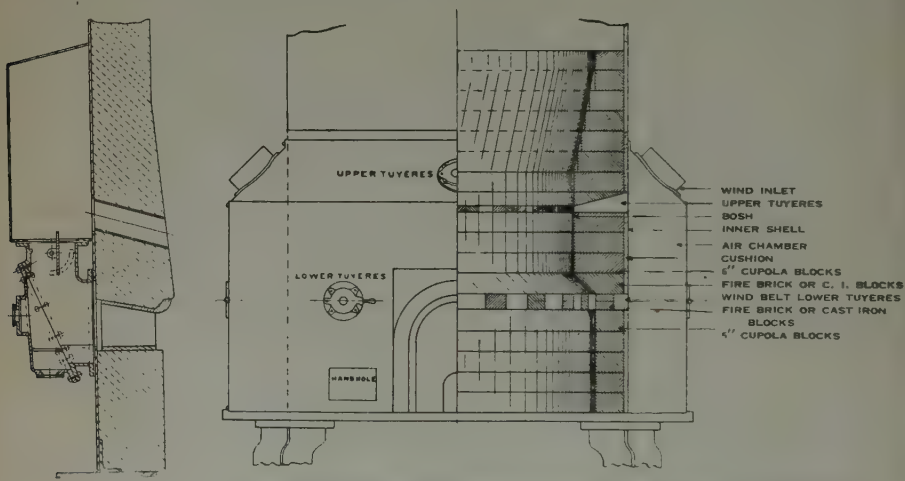


FIG. 19—(LEFT)—INSET ARRANGEMENT TO PERMIT SHORTER TAP HOLE THROUGH A THICKER LINING. FIG. 20—(RIGHT)—COMBINED SLAGGING SPOUT AND FETTLING DOOR FOR SMALLER CUPOLAS

of cast iron cracking under the hot conditions of service is urged against this material, while distortion and subsequent troubles is the chief objection to the use of steel. Experience shows that the danger of cracking cast iron doors is greatly exaggerated. This material is giving good service in thousands of cupolas. Cast iron T-section columns in the Whiting cupola, are splayed to facilitate opening the bottom doors and to permit easy removal of the dropped material. The splayed form removes the columns from contact with the incandescent fuel when the drop bottom doors are open, and in a large measure tends to reduce and eliminate this probable cause of cracking.

Columns usually are erected on a concrete foundation, with the foot of the column bolted through an open sand cast iron foundation plate. Usually the columns are tied together by suitable angles or rectangular mild steel bars, to prevent any laterial

displacement. In all cases it is advisable to cover the foundation bolts and tie rods with at least 6 inches of earth. Foundation arrangements of the columns are illustrated in Fig. 10. Mild steel rolled joist columns are illustrated in Fig. 11, and a further example of the use of cylindrical cast iron columns is illustrated in Fig. 13. This construction shows the cupola shell and wind belt supported on a square section mild steel foundation plate, bolted to cast iron polygonal section columns.



FIGS. 21 AND 22—DOUBLE TUYERE ARRANGEMENT TO PERMIT INTRODUCTION OF LARGER VOLUME OF AIR AT LOWER PRESSURES

Illustration Fig. 13, shows a simple form of mild steel bottom door attached to the foundation plate by simple hinges riveted in position. The mild steel bottom door illustrated in Fig. 11, is deserving of special mention. Distortion troubles likely to be encountered in the use of mild steel for this purpose are eliminated by double plate construction. The bottom doors are constructed of two semicircular plates built up by riveted stays, in a manner to form a hollow door effectively maintained cool by normal air circulation. The doors are riveted to angle iron hinges. A neat hinge is formed by a round bar and channel section members, riveted to the foundation plate as illustrated.

Substantial cast iron bottom doors hinged to the foundation plate of the cupola made by the Whiting Corp. are illustrated in

Fig. 10. Holes drilled in the bottom doors allow complete venting of the rammed sand hearth. Supporting columns of the cupola must be spaced sufficiently far apart to allow the bottom doors to swing freely. This is specially necessary where cast iron bottom doors are used.

Arrangements for locking the drop bottom doors in position and for easy opening without danger to the operators are of great importance. The simplest form of locking device is a prop

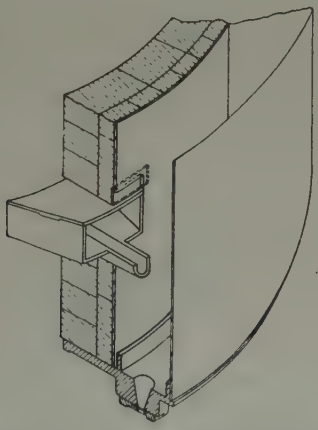


FIG. 23—STANDARD TYPE OF WIND BELT CONSTRUCTION

and wedge. Usually to facilitate removal of the prop a mild steel link is provided into which a long bar or the crane hook can be inserted to pull the prop away. A suitable snatch block is necessary when using the crane for this purpose. An elaboration of this simple prop illustrated in Fig. 14 is recommended by the Whiting Corp. A special foundation cap is provided with three props and a wedge. One prop is solid and the two outer props terminate in screw tops by which the bottom doors are locked tightly in position.

Method of raising the bottom doors of large cupolas by a chain passing over suitable pulley as illustrated can be operated from a standard air hoist or other suitable lifting arrangement. An ingenious and effective bottom door locking device in use on cupolas up to about 36 inches diameter is illustrated in Fig. 17.

A mild steel flat or T-section of sufficient length is provided with four slots at the requisite distance apart. This bar is inserted through T-slotted lugs in the foundation plate diametrically opposite each other along the joint of the semicircular doors. The sliding of this bar along until the slots in the bar enable it to freely fall away from the lugs in the foundation plate, is all that is necessary to free the locking bar and release the bottom doors.

Even in drop bottom cupolas in Great Britain the custom still

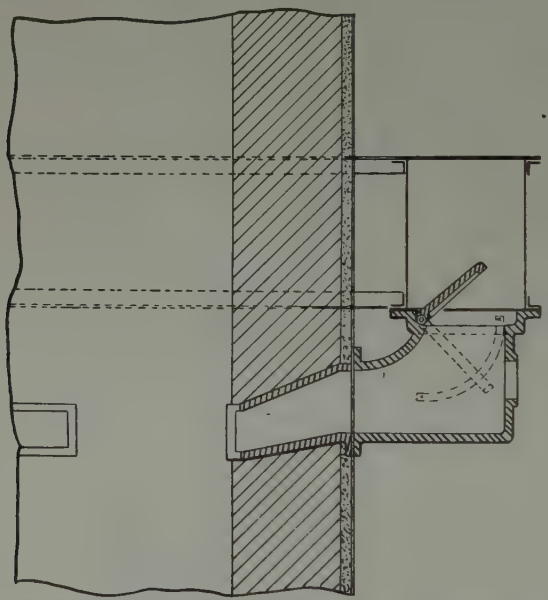


FIG. 24—ONE METHOD OF CONTROLLING THE AIR PASSING THROUGH THE TUYERES

obtains of providing a large opening in the cupola shell through which the hearth and bottom may be prepared upon the closed bottom doors. This opening referred to as the fettling door generally is located diametrically opposite the tapping spout, and also is arranged to support and include the slagging spout when the door is closed. No special reason beyond that of mere general convenience is responsible for a fettling door and slagging spout embodied in one and located diametrically opposite the tapping spout. They might just as well occupy some other position rela-

tive to the tapping spout providing always that the slagging spout is located between two tuyeres or the tuyere doors and never immediately below a single tuyere.

Slag and tapping spouts in the Whiting and Colliau types of cupolas are provided in the main shell at the required levels. The method of holding the tapping spout in position is shown in Fig. 18. The method adopted in these types of forming the tap hole can be arranged in other cupolas and is advantageous, particular-

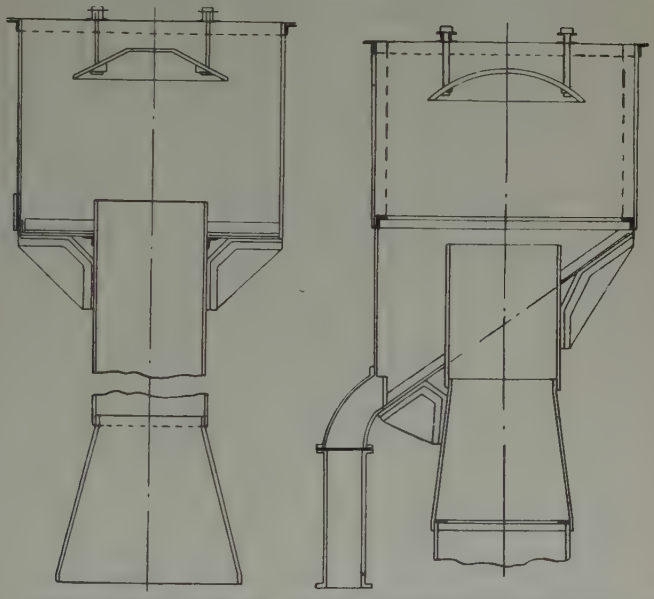


FIG. 25—(LEFT)—ONE TYPE OF SPARK ARRESTER USED ON A BRITISH CUPOLA. FIG. 26—(RIGHT)—A SPARK ARRESTER OF THE SELF CLEANING TYPE

ly in those cupolas where the lining is specially thick. The author favors the arrangement shown in Fig. 19. The lining is exceptionally thick and this arrangement allows the formation of a shorter tap hole. In this form of construction the breast and tap hole may be taken out and completely reconstructed in the middle of the heat. The manner in which this is done is described in a following chapter.

A simple form of slag hole arrangement consisting of an oval opening arranged at a suitable level in the cupola shell was

shown in Fig. 11. A suitable spout is bolted to the shell to conduct the slag away. The tap hole in this cupola is formed in a similar manner and a simple elongated hole is provided in the shell diametrically opposite the fettling door. The tapping and slag spouts generally are made of mild steel plate and are lined with suitable refractory material. Occasionally cast iron spouts are specified.

Two arrangements of fettling doors and clamping arrangements were shown in Figs. 11 and 13 respectively. In the Pneulec

Table I

MELTING RATE OF BRITISH AND AMERICAN CUPOLAS

BRITISH		BRITISH		AMERICAN			AMERICAN		
Shell Diam. Ins.	Rating Tons per Hour	Shell Diam. Ins.	Rating Tons per Hour	Shell Diam. Ins.	Lining Diam. Ins.	Rating Tons per Hour	Shell Diam. Ins.	Lining Diam. Ins.	Rating Tons per Hour
24	0.5– 1	30	1– 2	28	19	0.5	27	18	0.25– 0.5
30	1– 2	36	2– 3	35	26	1– 1.5	32	23	0.5– 1
36	2– 3	42	3– 4	42	33	2.5– 3.5	36	27	1– 2
42	3– 4	48	4– 5	49	37	4– 4.5	41	27	1– 2
48	4– 5	54	5– 6	54.5	42	6– 7	41	32	3– 5
54	5– 6	60	6– 8	58	46	7– 8	46	32	3– 5
60	6– 8	72	8–10	63	51	8–10	51	37	5– 6
72	8–10	84	10–12	67	55	10–12	56	42	6– 7
84	10–12	96	12–15	72	54	10–11	63	45	7– 9
96	12–15			76	58	11–12	66	48	9–10
				80	62	13–14	72	54	10–12
				84	66	15–16	78	60	12–14
				86	68	17–18	84	66	14–18
				91	73	18–20	90	72	18–21
				96	78	22–24	96	78	21–24
				102	84	25–27	102	84	24–27
				108	87	28–30	108	87	27–30

arrangement Figs. 11 and 31, the fettling door is held in position by a yoke bar and wedges. The alternative method using T-headed screws in the yoke bar, was shown in Fig. 15 on page 24.

The method used by the author for combining slagging spout and fettling door is shown in Fig. 20. This is a convenient method of arranging the slagging spout in smaller cupolas. Standard cupola arrangement provides for one tapping spout only, but more than one spout may be provided if necessary. These should be arranged at slightly different levels.

Simplest and most common form of wind belt construction, particularly in the smaller cupolas consists of an annular box of rectangular section arranged around the cupola shell as shown in

Fig. 11. The wind belt formed of flanged steel annular plates is riveted to angle iron rings attached to the cupola shell. Air enters through a double flanged inlet tube containing a simple butterfly valve, and attached to the casing of the wind belt, also provided with suitable tuyere doors, inspection and cleaning doors. In the wind belt illustrated in Fig. 10, holes are provided immediately underneath the tuyeres. They are closed by strips of sheet lead held in position by an annular cast iron flange bolted to the underside of the wind belt. The object is to prevent ac-

Table II

DIMENSIONS OF FRENCH STANDARD CUPOLAS

Tons per hour	1.96	2.94	3.92	4.80	5.88
Shell diameter, inches	37.4	48.5	56.75	60.7	63.0
Overall height, feet	27.0	29.0	30.0	32.0	36.0
Height of charging platform, feet	14.3	16.0	18.0	19.0	20.0
Thickness of shell, inches	0.236	0.236	0.275	0.275	0.275
Diameter of air inlet, inches	8.75	9.84	11.81	11.81	13.78
Diameter of forehearth, inches	43.0	49.0	55.0	58.0	60.0
Height of forehearth, inches	43.0	43.0	47.0	47.0	49.0
Thickness of forehearth shell, inches	0.236	0.236	0.275	0.275	0.275

cumulation of molten slag in the wind belt due to accidental rising of metal and slag above the tuyere level.

A similar form of wind belt, illustrated in Fig. 15, is divided vertically at a point diametrically opposite the air inlet. A baffle plate at the air inlet and clearly shown in the illustration, divides the air supply into both sections of the belt.

In the older cupolas possessing two rows of tuyeres, the wind belt usually was divided about the horizontal plane into two sections containing the upper and lower tuyeres respectively. Air from the main air supply was supplied to each section separately, by a breeches pipe. A separate main air control valve was provided for each section for the air belt.

A special form of wind belt construction fairly common on some of the larger types of standard cupolas is illustrated in Fig. 31. The wind belt is formed of a pipe from which the tuyeres are dropped by a modified form of blast furnace goose neck. Inspection covers are provided on each separate tuyere. It is claimed that a much smoother flow of air is obtained from this construction. A resemblance may be noted between this and the Whiting special cupola construction illustrated in Fig. 10.

Wind belt and tuyere control on the standard series of

French cupolas previously referred to is illustrated in Fig. 24. The simple and effective nature of this tuyere control is clearly evident from the illustration.

The Whiting standard wind belt construction illustrated in Fig. 23 is built up from the specially flanged foundation plate to a conical slope on the top surface. This conical surface prevents the lodgment of dirt and water at this point and consequent cor-

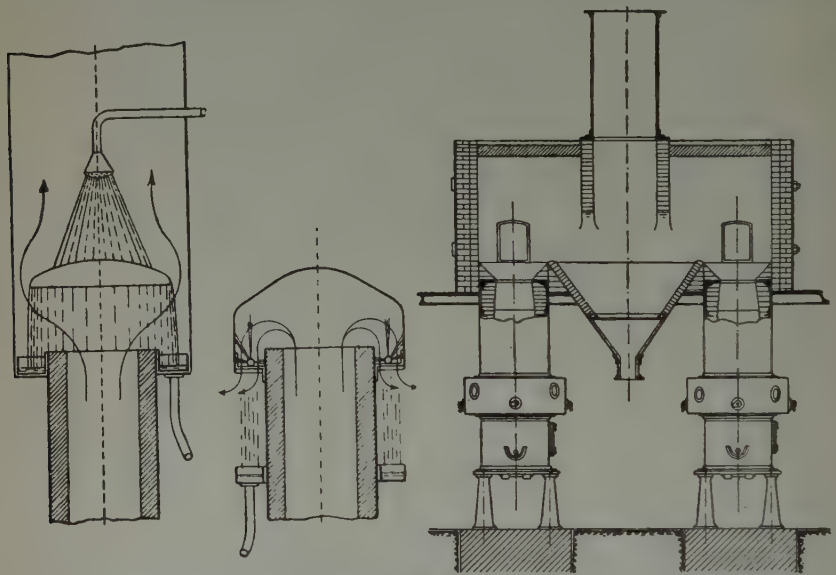


FIG. 27—(LEFT)—A WATER SPRAY TYPE SPARK ARRESTER. FIG. 28—(RIGHT) —EXPANSION CHAMBER SPARK ARRESTER

rosion on cupolas in exposed positions. This feature also is adopted in the Colliau and Titan types. In the latter the wind belt is welded to the cupola shell.

In the American cupola shown in Fig. 12, the wind belt is constructed independently of the base plate. The bottom is made up of cast iron plates with a flanged steel top and sheet steel sides. All the joints are made tight with sheet asbestos. The wind belt is provided with the necessary cleaning doors and tuyere inspection covers. The wind belt in cupolas up to 60 inches in diameter need not exceed ¼-inch thickness of plate. Above 60 inches diameter 5/16-inch plate is used. Closer riveting at 2½-inch

Table III

PRINCIPAL DIMENSIONS TYPICAL BRITISH AND AMERICAN CUPOLAS

		Total Height Ft.	Height of Charge Door Ft.	Height Columns Ft.	Size of Charge Door Inches	Diam. of Air Belt Ins.	Rows of Tuyeres	Diam. of Air Inlet Ins.
PAXSON-COLLIAU	32	28	11.0	3.0	To Suit Particular Requirements	40	2	
	28	32	12.0	3.0		49	2	
	24	35	13.0	3.0		58	2	
	20	35	14.0	3.5		65	2	
	16	35	14.5	3.5		74	2	
	14	35	14.5	4.0		78	2	
	12	35	15.0	4.0		83	2	
	10	35	15.0	4.0		88	2	
	9	35	15.5	4.5		92	2	
	8	35	15.5	4.5		100	2	
	6	35	16.0	4.5		104	2	
	5	35	16.0	5.0		106	2	
	4	35	16.5	5.0		107	2	
	2	35	16.5	5.0		112	2	
	1½	35	17.0	5.5		116	2	
	1	35	17.0	5.5		123	2	
	0	35	20.0	6.0		132	2	
WHITING	0	To Suit Particular Requirements	As High as Possible with Due Consideration of Size of Heats	...	.....	..	2	.....
	1			2.0	15 x 16 (1)	46	2	6.375
	2			2.0	20 x 20 (2)	50	2	10.00
	2½A			2.5	22 x 22 (1)	57	2	11.75
	2½B			2.5	22 x 22 (1)	57	2	11.75
	3			2.5	24 x 23 (1)	62	2	14.00
	3½			3.0	27 x 29 (1)	67	2	14.00
	4			3.0	27 x 30 (1)	74	2	14.00
	5			3.5	27 x 30 (1)	81	2	17.00
	6			3.5	27 x 30 (2)	84	2	17.00
	7			4.0	27 x 35 (2)	92	2	18.125
	8			4.0	27 x 35 (2)	98	2	18.125
	9			4.5	27 x 35 (2)	104	2	24.875
	9½			4.5	27 x 35 (2)	112	2	24.875
	10			5.0	27 x 35 (2)	118	2	24.875
	11			5.0	27 x 35 (2)	124½	2	24.875
	12			Special	27 x 35 (3)	131	2	30.09.
TITAN	2	18.5	13	Particular ements	20.5 x 20.5	42	1	7
	3	21	15		20.5 x 20.5	48	1	8
	4	23	16		23 x 23	54	1	10
	5	25.5	18.5		23 x 23	60	1	12
	6	26.6	20		26 x 26	66	1	15
	8	28.6	20.5		26 x 26	72	1	16
	10	33	23		30 x 30	96	1	20
	12	36	24		36 x 36	108	1	24
RAPID	2	22.3	16.5	To Suit Requir	To Suit Particular Requirements	41	2	7
	3	24	17.5			49	2	10
	4	24.6	18.5			58	2	10
	5	25.8	19.5			68	2	12
	6	26.6	20.5			74	2	12
	8	28.6	22.5			80	2	14
	10	33.0	24			96	2	16

pitch is necessary in riveted constructions to render the wind belt air tight. Total internal volume of the wind belt chamber should equal at least one second's supply of air in cubic feet.

Air inlet generally adopted is a single inlet of large enough diameter to pass the requisite quantity of air. An air main control valve of the simple butterfly type is provided. In the Whit-

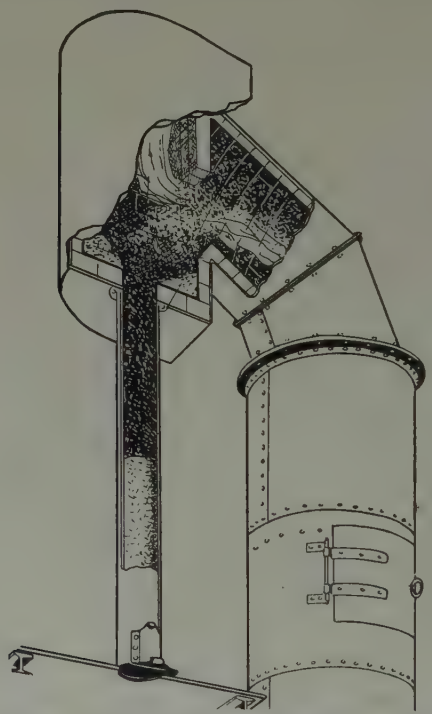


FIG. 29—A SPARK ARRESTER WHICH CARRIES THE DUST AWAY

ing cupola, the air inlet is attached tangentially to the wind belt. In the Paxson-Colliau cupola the air enters through two openings which are placed in the upper surface of the wind box.

Standard cupolas vary extensively in shape and number of tuyeres. Most makers adopt two rows of tuyeres as standard. The Stewart cupola for a time extensively quoted in textbooks carried three rows of tuyeres, but this arrangement now appears

to be abandoned. Several makers are adopting a single row of tuyeres only as standard. Dimensions of these are large enough to allow sufficient volume of air to be admitted to the cupola.

The Whiting cupola has standardized two rows of tuyeres. The bottom row, rectangular in shape, expands through a small area to a large opening inside the cupola. Internal area of these tuyeres is approximately double that of the area on the external surface, and the internal openings form an almost continuous belt around the cupola. The upper row of tuyeres similar in construction to the lower, are intended to supply sufficient air to utilize to the fullest extent any escaping fuel gases. A simple form of individual damper for regulating purposes is provided.

Two of the bottom row of six tuyeres in the Whiting cupola are equipped with spouts through which the slag or iron will flow before it reaches any of the other tuyeres. See Fig. 23. The spout leads the overflow to a hole in the bottom plate of the wind belt. This hole usually is covered with a sheet of lead through which the hot slag or iron readily penetrates. Hinged covers fitted with mica covered peepholes are provided in the wind belt casing, immediately opposite each tuyere to permit of examination and cleaning.

In the adjustable tuyere system on the special Whiting cupola illustrated in Fig. 21, the lower tuyeres consist of three parts: (1) Tuyere cover, a continuous set of segments that interlock with each other. (2) Tuyere cover supported by the triangular vertical section of the base plate. (3) Adjustable side plates. The circular upper tuyeres of this special cupola slope downward.

Paxson-Colliau tuyeres are similar to the Whiting in the bottom row. The top row of circular tuyeres tapers to the inner surface as illustrated in Fig. 12. Tuyere covers for the top row are arranged on the sloping top of the wind belt. A special system of tuyeres in conjunction with a boshed construction of the tuyere zone in the Paxson cupola and illustrated in Fig. 22 is designed for the introduction of a large volume of air into the melting zone at low pressure and velocity.

A venturi shaped arrangement is adopted in the Thwaite

Rapid type of cupola in both rows of tuyeres. A single row of tuyeres of rectangular section flared to the inner diameter of the cupola is the standard construction on the Titan cupolas.

Generally speaking, the tuyeres are supplied as iron castings, bolted on the interior of the cupola shell. Individual damper con-

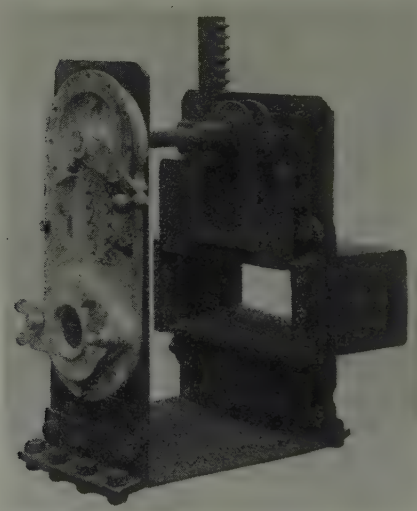


FIG. 30—RACK AND PINION TYPE TUYERE SHUTTER

trol is fitted to most modern cupolas. Arrangement of the Davis damper, a sliding shutter operated by a rod drilled at intervals for varying degrees of opening is illustrated in Fig. 13. A substantial form of sliding shutter operated by a rack and pinion is illustrated in Fig. 30. A tuyere damper of the guillotine type is adopted on the Titan cupola. An ingenious double sight hole which permits poking and observation of the tuyeres to be carried out simultaneously also is supplied on cupolas made by the Constructional Engineering Co., Birmingham.

Apart from danger arising from sparks carried away from cupolas in populated areas, saving in cost in the maintenance of roof lights and roof drainage in modern foundry buildings by the installation of spark arrestors is becoming increasingly realized.

Various spark arrestors have been adopted, all of which are

of the simplest type. Economy of the cupola plant does not permit installation of the elaborate dust extracting appliances found in blast furnace plants. The spark arrestors generally employed present an adaption of some form of expansion chamber on top of the cupola, generally in combination with a baffle plate ar-

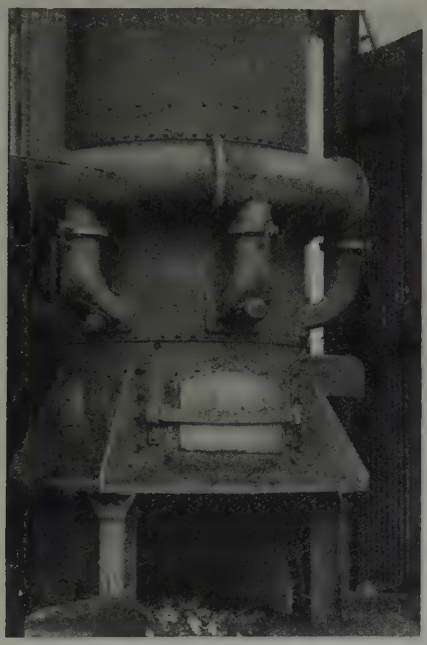


FIG. 31—SPECIAL CAST-IRON WIND BELT AND TUYERES

rangement. Expansion reduces velocity of gases carrying the sparks and allows the earthy matter and sparks to be deposited where provision is made for accumulation and withdrawal of the material. Analysis of the sparks collected from a cupola plant in this manner follows:

Carbon 47.44 per cent (chiefly coke dust)
Silica 37.75 per cent (chiefly sand)
Iron oxide 12.25 per cent
Lime 2.00 per cent
Magnesia 0.56 per cent

A simple type of expansion chamber diagrammatically illustrated in Fig. 28 is arranged for two cupolas. Gases from the cupolas are discharged into a large and substantially built brick chamber. Reduction in the velocity of these gases allows the deposition of sparks and dust and this is assisted further by the

Table IV

TYPICAL LEADING DIMENSIONS OF CUPOLETS

Capacity per hr., hundredweight	Total height from floor, feet	Outside diameter, inches	Inside diameter, inches	Total weight, tons
5 to 10	6.0	24	18	11
10 to 15	9.25	24	18	15
15 to 20	9.5	27	20	17
30 to 40	9.25	36	23	22.5

baffle walls built around the chimney-like exit provided to the chamber. A conical chamber provided for collection of dust leads to a pipe extension provided for the removal. The angle of this chamber should not be less than 55 degrees to allow free flow of collected material. The chimney exit preferably should be covered in a manner to prevent the entry of rain which is rapidly absorbed by the dust and prevents its easy removal. A chamber of this nature usually is constructed of firebrick and reinforced by suitably disposed tie rods. Weight of the whole structure necessitates substantial superstructure. This probably is the most effective spark arrestor but its first cost is high.

Simplest form of spark arrestor is an inverted, dished baffle plate attached to the top of the cupola and arranged to deflect the sparks into an annular cavity arranged round the top of the cupola as illustrated in Fig. 25. This type is employed extensively on small cupolas used intermittently for short periods. An elaboration on this form, illustrated in Fig. 26, provides means for the withdrawal of the collected material.

The Osborn type spark arrestor illustrated as applied to a single cupola in Fig. 29 has been extensively adopted in Great Britain. It is really a compact form of an expansion chamber and baffle plate construction with means for removal of the deposited material. These latter types are comparatively inexpensive since they do not need the heavy superstructure necessary for the brick chamber referred to previously.

In totally different types of spark arrestors illustrated in Fig. 27 the sparks are arrested and quenched by a spray of water. Their action is clearly depicted in the diagrams. The author has no experience of their practical use, but it is evident that ample

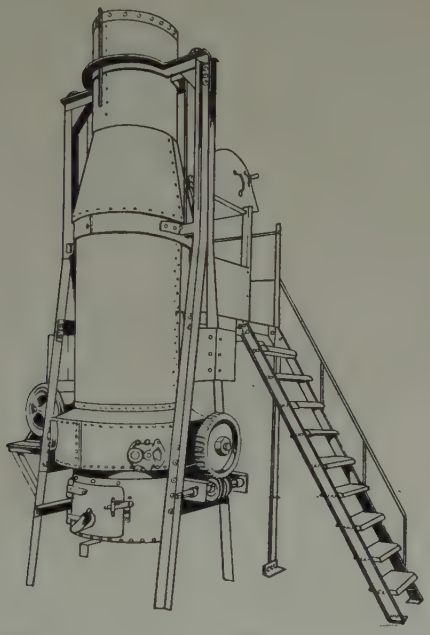


FIG. 32—A SMALL TILTING TYPE CUPOLA

exit waterways will be required to prevent stoppage from accumulative sludge material.

What might be regarded as miniature cupolas are standardized by cupola builders for special experimental uses, and for use in temporary situations. These cupolas generally are referred to as cupolets or dwarf cupolas. Their melting capacity varies from 1000 to 3000 pounds per hour, and they are extremely simple in design consisting of a mild steel shell supported on cast iron trunnions and *A* frames. Two tuyeres are arranged to pass through the hollow trunnion spindles, and are provided with a simple shutter type blast gate and peephole doors with mica inspection windows. For convenience in cleaning and relining the smaller

diameter units, the whole shell can be tilted to a horizontal position on the trunnions. A hinged steel leg is provided to support the shell in this position. The cupola is equipped with a solid cast iron hinged drop bottom door well drilled for venting purposes. The ganister or silicious fire clay lining is rammed around a wood pattern of the requisite diameter. Typical standard dimensions of a series of baby cupolas is given in Table IV and an illustration of a complete unit with fan and blast pipes is shown in Fig. 32. These cupolas are used in small foundries, for experimental purposes, and they can be mounted on carriages or rollers to form portable units.

CHAPTER III

Operation

Smooth operation important—Preparation of the cupola—Chipping out—Daubing—Making up the bottom—The tap hole—The fettling breast and slag hole—The tapping spout—Charging the cupola—The bed coke—Metal charges—Melting the iron—The slag hole—Dumping the cupola—Scaffolding or bridging—Banking the cupola—Special purpose devices—Slag separating devices—Automatic tap hole closing—Slag buckets—Pig breaking machines—Weighing machinery—Erection and maintenance of the cupola.

GETTING the best out of a cupola does not end with melting the hottest iron or with the lowest coke consumption. Smoothness of operation, freedom from detail troubles, tap hole trouble, scaffolding, breakouts, operation with the minimum damage to the lining and repair work are all equally important in the efficient operation of the cupola.

In practically every respect, cupola practice is an art and the personal intelligence, skill and experience of the operator are finally responsible for the continued efficient operation of the cupola under any particular circumstances. Cupola detail practice varies in individual foundries and it is impossible in a description of this nature to do more than deal with the more important of the details and methods involved. This can be done most conveniently by dividing the subject into four sections under the following subheadings: (a) Preparation of the cupola for charging; (b) charging the cupola; (c) melting the iron; (d) special purpose devices.

The first job in the preparation of the cupola after clearing away and sorting the dump from the previous day's melt, is to chip out the excessively large lumps of slag and cinder material adhering to the lining. This is followed by daubing or coating the lining up to the melting zone region with refractory material. If the slaggy projections are allowed to remain, they are likely to increase in size after continued melting, and ultimately cause scaffolding or bridging. The larger lumps of material, usually found above the tuyere openings, generally are removed by prodding and poking with a long heavy bar, with

or without the assistance of a sledge hammer. The smaller soft and porous accumulations and all hard slag projections are removed by the operator inside the cupola, armed with a sharp pointed, short handled pick.

It is not necessary to chip off the smooth coating of slag, covering the lining, but it is good practice to penetrate this coating at intervals with the sharp pointed pick. This gives the daubing material, subsequently applied, the opportunity of adhering to the underlying brickwork. The practical operator before commencing the chipping operation invariably sluices the walls of a dry cupola with water. This precaution alleviates the personal inconvenience caused by dust. It is also advisable, particularly when other workmen are present, to close the charge hole doors, or to provide a shield across the cupola shaft above the operator to prevent stray bricks or other material falling down the shaft.

After the chipping operation, the lining is coated from the hearth to above the melting zone with a refractory plastic material. Ganister, or a fireclay and sand mixture, with sufficient water added to make into a plastic mass, are the materials commonly used for this purpose. In the course of the melting operation, the cupola lining invariably is corroded by the action of the heat and the slag forming materials, particularly in the region of the melting zone. The principal object of the daubing operation is to make good this corrosion and restore the lining to its original shape. At the same time, all special defects, such as loose bricks, large holes, caused either in melting or chipping out, are repaired and a smooth lining of the desired shape obtained.

Plastic material used, should be highly refractory and at the same time, sufficiently plastic to adhere to the walls and form a hard lining of substantial mechanical strength after firing. The plastic material should be sufficiently wetted with water to enable it to be thrown on the lining by hand, with considerable force, to enable the material to penetrate any cracks and the joints of the brickwork. When the whole of the lining has been covered in this manner, the plastic material is smoothed with a trowel. The author prefers to use daubing material in the

dryest possible state in which it can be used, without loss of plasticity. The material can be spread, or forced on by hand, or rammed and tamped with a wooden rammer.

Before the plastic material is applied, the lining is wetted thoroughly with clay wash. Large holes are filled with pieces of broken firebrick and plastic material. Good practice favors stopping even small holes with broken firebrick, rather than with plastic material. After the plastic material is applied and smoothed, some men favor copious venting by piercing the layer of daubed material with a 3/16-inch to 1/4-inch diameter, sharpened spike. This never can do any harm and assists in preventing the material from cracking and flaking off during the drying period when the steam is escaping. The daubing never should be too thick. It is advisable to maintain an average thickness not exceeding 1 inch. To prevent the need for excessive daubing this operation is carried out systematically before every melt.

With the daubing finished, the next operation is to make the sand bottom. The bottom doors are closed and locked in position, either by the usual prop and wedge, or other form of locking device provided. The bottom doors usually are closed by hand although various devices have been developed for this purpose particularly for use on the larger cupolas.

Making up the sand bottom is an operation which requires great care. Nothing is more annoying, irrespective of the danger arising therefrom, than a leak or a breakout of the molten metal through the bottom doors. The choice of refractory materials for this purpose is limited practically to a good bonded sand. Fireclay, or other materials with a large clay content, set so hard under the influence of the heat, that difficulty is experienced in dropping the bottom and getting the material out of the cupola when the melting operation is finished. Some operators lute the bottom door joints with fireclay as a precautionary measure, although this is not really necessary if the sand bottom is well made.

Good tough molding sand, is thrown on the closed bottom doors and carefully rammed particularly around the circumference and across the center joint to a minimum depth of about 3 inches. The bottom is arranged to slope upward from the tap hole about

½ to 1 inch to the foot. In cupolas with two tap holes, the bottom is sloped to lead to both. Care always should be exercised not to make the bottom hollow, or saucer shaped. This is a frequent source of breakouts. The ramming should be done carefully, not too hard, but exactly as in a hard rammed mold. The surface then is smoothed carefully with a trowel and any soft spots made good and hard. Some foundrymen still cling to the antiquated clay wash finish on the bottom, but the practice is not favored by the new school of melters.

Forming the tap hole depends upon the particular arrangement of the cupola. In some cupolas, the tap hole is embodied in a large hole or breast, which requires to be closed by a suitable breast plate after the cupola is lighted. Generally, the tap hole opening in a modern standard cupola is small and the tap hole is formed by ramming a mixture of fireclay and sand, around a taper rod placed in the opening in the brickwork. The clay mixture is rammed tightly in position, and the hole is made about 2 inches diameter on the outside, tapering down to about ¾-inch or ⅝-inch on the inside.

Many operators prefer a parallel tap hole about 1 inch diameter. They cut away the front portion of the rammed material to leave a hole 2 to 3 inches in length. When the blast is put on, the tap hole is left open, and the flame issuing through the hole dries the clay material and burns it to a degree of hardness sufficient to withstand the continued prodding and poking of the tapping bar. In good practice a quantity of plumbago, or ordinary foundry blacking is mixed with the fireclay and sand. Iron and slag are less likely to stick in a tap hole of this kind. Specially burnt firebricks, or bricks made of material similar to that in plumbago crucibles, are manufactured with the tap hole embodied. One can be built into the brickwork to form a permanent tap hole. In a cupola with a large breast opening, the breast and tap hole are filled in exactly the same manner as the fettling breast and slag hole to be described later. The tap hole requires more careful preparation of course than that used in the slag hole.

With most cupolas either a tap hole breast or a fettling breast is provided for the convenience of the operator making

up the bottom and the inside of the tap hole after closing the bottom doors. This breast is filled in after the fire has been lighted and a portion of the bed coke charged on the bottom of the cupola.

The manner of filling the breast is shown in the illustration

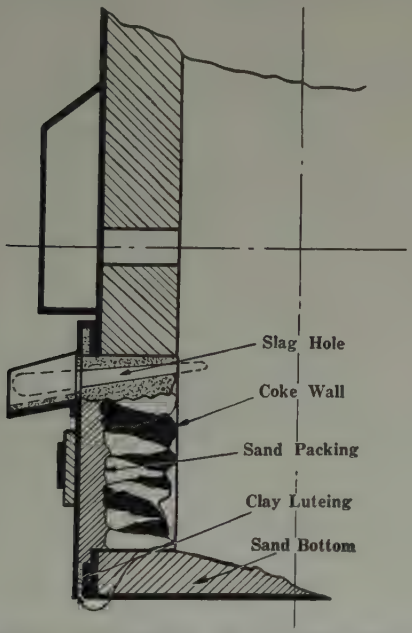


FIG. 33—ILLUSTRATING THE METHOD OF CLOSING FETTLING BREAST AND SLAG HOLE

Fig. 33. A wall is built from selected pieces of coke. Where a slag hole is required, it is formed in like manner to the tap hole round a taper bar, placed in the desired position. The coke wall, wetted with clay water, is covered with a layer of tough molding sand, or black sand from the foundry floor. The breast plate, luted round the edges with fireclay, is placed in position and forced tightly against the sand, by wedges, T-head screws and a yoke bar, or other form of locking device. Tightening the breast plate consolidates the sand against the coke wall, making a tight and safe closure.

The tapping spout is lined preferably with good loamy sand,

rammed into position. An even slope should be made without hollows in which the metal stream can lodge, and it is advisable to originate the lining of the tapping spout from a point about 1 inch below the bottom of the tap hole. This is indicated in Fig. 19, Chap. II, and shows clearly how the tap hole may be botted. The tapping spout should be given a good coating of blackwash and carefully dried by lighting a wood fire along its length. This concludes the preparation. The cupola then is ready for charging and melting.

Under the conditions of operation in a shaft furnace in which the air is injected into a column of incandescent coke, a definite zone is established over which the temperature attained by the combustion is at a maximum. This zone is referred to as the melting zone, and is at a higher level than that of the top tuyeres. Existence and character of this melting zone are discussed more fully in a later chapter. Sufficient to point out at this stage that if the melting zone assumes a well defined upper limit under any given conditions, then the initial bed coke should be charged up to this level. Additional coke charges should be sufficient in amount to replenish that part of the bed burned away in melting the iron charge. If the initial bed coke charge is higher than this limit, the initial melting will occupy a longer time, and the iron possibly will be cold. If the bed coke height is less than this limit, the iron will be cold, and danger of scaffolding is imminent, due to unmelted metal getting down into the tuyere zone.

The upper limit of the melting zone in any given cupola is determined by a number of conditions including temperature, pressure and velocity of blast, character of coke, combustibility, ash content and the like. Influencing factors are so many, correct height of the bed coke cannot be stated dogmatically. Determination should be a matter of actual experiment for every individual cupola. In the words of Kirk "To do good melting, the melting point must be discovered and only a sufficient quantity of fuel placed on the bed to bring the top of the bed up to the melting point."

To ascertain the correct height of the bed coke the ob-

server notes the time from putting on the blast to the commencement of melting. This time should not exceed 10 to 12 minutes. If the time is unduly long, the bed coke is too high. If the iron appears in less time but is dull and cold, the bed coke is too low.

These observations on the correct height received general confirmation from appearance of the burnt out portion of the cupola wall after melting. This locates and fixes the height of the melting zone. From many observations the general rule is that the bed should be from 8 to 12 inches above the top tuyeres. In ascertaining the correct height for any individual cupola good practice suggests starting somewhat higher than this, and gradually reducing the height to the minimum possible without affecting the temperature and character of the iron. Height of the bed coke can be ascertained readily by using a light rod cut to the required length and inserted through the charge hole.

A large portion of the bed coke generally is charged and the fettling or tap hole breasts are not closed finally until this is well alight up to the tuyere level. Before any further charging takes place, it is desirable that the bed coke shall be thoroughly alight. The tuyere doors are allowed to remain open to promote a natural draft through the stack. Where for any reason this process is too slow the speed of burning often is increased by the introduction of an air blast. This can be introduced through the slag hole or through a special tuyere, technically known as a kindling tuyere provided at a low level for this purpose. This tuyere must be stopped with fireclay when melting commences. The regular blower sometimes is used, either throttled down or with the blast gate in the pipe nearly closed. Oil burners also have been recommended for igniting the bed coke. The breast is left open for the application of the burner and is not closed until the bed is well alight.

The metal portion of the cupola charge consists of pig iron and scrap iron, or steel of various sorts. With each charge, or with a given number of charges, a quantity of limestone is added to flux the sand on the pig iron, and the coke ash. A charge of coke is required to replenish that part of the bed burned in melting each charge of iron.

The first charge of iron is placed on the well lighted bed, followed by its quota of coke. Succeeding charges of iron and coke follow in alternate layers until the stack is filled to the charging door sill. It is still common practice to make the first charge of iron heavier than those which follow it. In some places the first charge is doubled. No good reason can be adduced in defense of this practice. The object of good charging, is evenly distributed layers of iron and coke. Owing to the observed tendency of the flames to creep up the sides of the cupola, it is probably desirable to distribute the charge toward the outer circumference.

Table V

LIMIT THE WEIGHT OF METAL

Diameter, inches	Area, Sq. Ft.	Volume of coke in melting zone, Cu. Ft.	Weight of coke in melting zone, Lbs.	Limiting Wt. of metal charges, Lbs
10	0.5	0.5	15	150
20	2.25	2.25	67.5	675
30	5	5	150	1,500
40	9	9	270	2,700
50	13.6	13.6	408	4,080
60	20	20	600	6,000

Weight of individual metal charges vary according to the diameter of the cupola. They should never exceed the maximum weight of metal that would be melted by the coke contained in the melting zone. The accompanying Table V indicates the limiting weights of individual charges in various cupola diameters. The table is based on the assumption that the average depth of coke in the melting zone is 1 foot and that 1 pound of coke will melt 10 pounds of iron. Weight per cubic foot of piled coke varies between 28 and 40 pounds. A value of 30 pounds per cubic foot has been used in the table.

Recent experiments on the continent have demonstrated the most suitable height of the coke charge to be about 0.59 feet. On the assumption of this value as the minimum thickness of the coke charge layers, the weights of the metal charges for different diameter cupolas have been calculated.

Pig iron and scrap portions of the charge are never desirable in large individual sizes, although, of course, this always cannot be avoided. The pig iron preferably should be used in quarter pigs, and the scrap in small convenient sizes.

The amount of limestone necessary will depend largely on the ash content of the coke and the relative cleanliness of the scrap. Excess limestone should be avoided as it invariably tends to corrode the lining. Amount of limestone varies from 6 to 10 pounds per 100 pounds of coke charged. The limestone is broken to about the size of ordinary road chippings. Other fluxes such as fluorspar and alkali salts are used for special purposes. These are discussed more fully in a later chapter.

In selecting the most suitable coke the following points should be noted: Sulphur content, ash content, moisture content, mechanical strength, average size. The sulphur content should not exceed 1 per cent and the moisture 2 per cent. The amount of ash decreases the heat value per unit weight of coke and increases the quantity of limestone necessary for fluxing purposes. Coke should be sufficiently strong to resist handling, charging and the burden of the charges.

General practice leaves the tap hole open after the blast has been put on and allows the molten metal to trickle through until it appears hot and fluid. The tap hole then is stopped by a clay bot, carried on the flattened upset end of a round steel bar, called the botting stick.

A sharp pointed steel rod is used to tap out the metal. Care should be taken to stop the tap hole immediately when signs of slag make their appearance. Tapping becomes extremely difficult when a quantity of slag is allowed to get into the tap hole. The tuyeres should be kept clean and free from chilled slag which tends to accumulate and overhang them in the front and immediately above. This is done by poking with an iron bar. Care always should be taken to prevent slag and metal overflowing through the tuyeres into the windbelt. Considerations of pressure and volume of blast are of vital importance in successful melting and are dealt with fully in a subsequent chapter.

Melting is continued, and as the charges sink in the stack, they are renewed constantly by fresh material according to the demands of the foundry. Should the demand cease temporarily, melting may be stopped or slowed by reducing the quantity of

blast. If for any reason this temporary stoppage is likely to be extended, the metal lying in the hearth of the cupola should be tapped out. If it is allowed to stay in the hearth too long it will freeze in the tap hole and cause delay and trouble when melting is resumed.

Some operators prefer to keep the slag hole open throughout the entire heat while others prefer to open it at regular intervals. In long daily melts, it certainly is safer to keep the slag hole open and thus obviate the necessity for constant watchfulness on the part of the attendant to prevent the over accumulation of slag. With continued melting, the quantity of slag increases and this can be removed only by keeping the metal in the hearth sufficiently high to float it off through the slag notch.

When the melting is completed, the tap hole is left open and all the slag and remaining liquid iron in the bottom of the cupola is allowed to drain off. The locking device or the prop and wedge under the bottom doors then is removed, allowing the bottom doors to fall open. When a prop is used, a link generally is attached to the bottom of the prop into which the hook of a chain can be inserted to pull it away in safety.

If the bottom has been well made, there should be plenty of time to remove the locking device safely, and no sudden dropping or splashing of the material need be anticipated. Upper layers of the sand bottom generally are fused together into a viscous, glassy mass and usually some seconds elapse before the weight of the material remaining in the cupola penetrates this. A few trickles of slag and metal are followed by the sagging of the fused bottom which ultimately breaks and allows the material to fall through.

In common practice the dump falls on a cast-iron or steel tray which readily can be pulled from under the cupola by the crane. The chain or cable passes through a snatch block anchored in the floor for the purpose. Special dump cars, mounted on bogie wheels are employed in some places. Dumped material remaining under the cupola is quenched with water, particularly around the supporting columns

and any large lumps of material adhering to the sides of the cupola are removed by a long bar. After this dumped material has cooled, it is removed from underneath the cupola. Unburnt coke and metal are sorted out and returned to the stock piles.

Scaffolding probably is the most serious trouble likely to be encountered in normal melting practice. Through various reasons the charges above the tuyeres may be prevented from descending by the formation of a more or less solid arch of partially solidified slag and metal. The coke in the bed burns away from underneath thus leaving all the charges suspended in the cupola shaft. This is a serious state of affairs, for if the metal cannot be melted out, it is a laborious task to remove it by any other means.

The principal cause of scaffolding is the formation of lumps of hard solidified slag immediately above the tuyeres which prevent the uniform settling of the charge. Other causes are: (a) projections remaining on the side of the cupola, resulting from bad fettling; (b) falling in of the daubing material; (c) pieces of metal of too large a size; (d) choked tuyeres which interfere with the blast supply; (e) dirty scrap and insufficient flux.

If the bed coke has not burned away too much, a scaffold generally can be removed by introducing coal into the furnace through the tuyeres. Sufficient coal, easy ignition and long flame, generally will cure the most obstinate scaffold. Scaffolding, particularly that due to the formation of lumps over a tuyere or a piece of metal getting in front of a tuyere usually can be cured if caught in time, by closing the offending tuyere for a short period. This treatment generally melts out the obstruction.

Many cupola attendants do not know the cupola may be banked for a fairly prolonged period and restarted without the necessity for dropping the bottom. This practice is fairly common, particularly in continuous plants where the cupola is shut down for the noon hour. To do this effectively, the cupola should be provided with a tap hole breast and plate. The entire charges preferably should be melted down and tapped out of the cupola, although this is by no means necessary if the tuyeres are provided

with dampers which can be closed effectively. The liquid metal remaining in the cupola well should be tapped out. In anticipation of a long shut down the tap hole breast should be removed and the slag allowed to drain out. The breast then can be closed temporarily by a metal plate and the tuyeres closed by the dampers to prevent the natural draft of the cupola from melting the remaining charges. When ready to make a new start, the breast can be built up again, and the tap hole remade in the usual manner. The tap hole is re-dried almost immediately

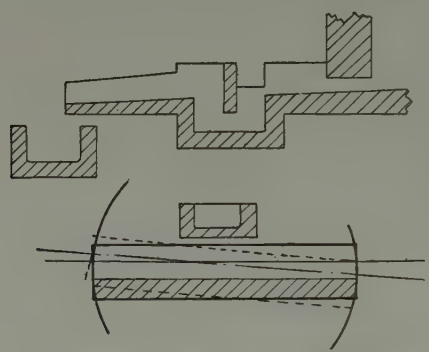


FIG. 34—SIMPLE SLAG SEPARATING DEVICE

after the blast is re-started and melting can be continued. It is advisable to increase the coke charges slightly for the first few charges, to make good any extra losses incurred during the banking up period.

Several special purpose devices resorted to in special cupola practice are dealt with in this chapter. The most common are the slag separating devices. Probably the earliest form of slag separating spout is that shown in Fig. 34 and used in agricultural and light machinery foundries where the cupola stream runs continuously all day.

When molten metal flows into the basin the slag on top of the metal is held back by the bridge and flows off through the slag notch on the side of the spout. While the furnace is in operation, the top of the slag chamber is covered with a flat, fire-brick tile. It is practically impossible for the slag, resting as it does on top of the metal, to pass the bridge, into the mix-

ing ladle. At the close of the heat, the metal in the basin is tapped through a hole in the side and drained off.

Continuous operation with this type of spout is facilitated by a tilting extension shown diagrammatically in Fig. 35. A re-

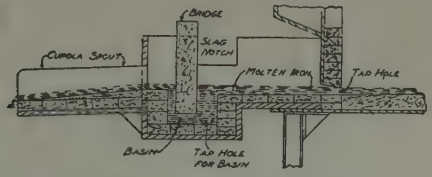


FIG. 35—SECTIONAL VIEW OF SLAGGING SPOUT

fractory lined spout is mounted pivotally at right angles to the main spout. This arrangement can be used continuously for filling ladles brought into position on either side of the tilting extension and thus prevent the splashing and waste which inevitably occurs with a continuous metal stream while changing the ladles.

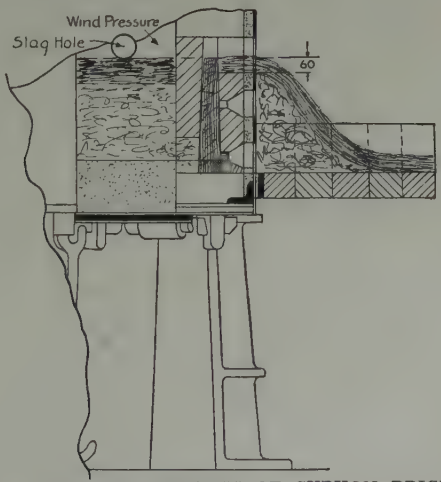


FIG. 36—ARRANGEMENT OF SYPHON BRICK

A more modern slag separating device has been developed by E. V. Ronceray and forms the basis of several devices now in use for removing slag from the metal stream. Action of this device and its construction are shown in the illustration,

Fig. 36. The bottom tap hole is used for emptying the cupola and syphon. A syphon brick forms the basis of most of the slag separating devices which have been embodied in the various special receiver designs to be described later.

An interesting mechanical tapping device shown in Fig. 37

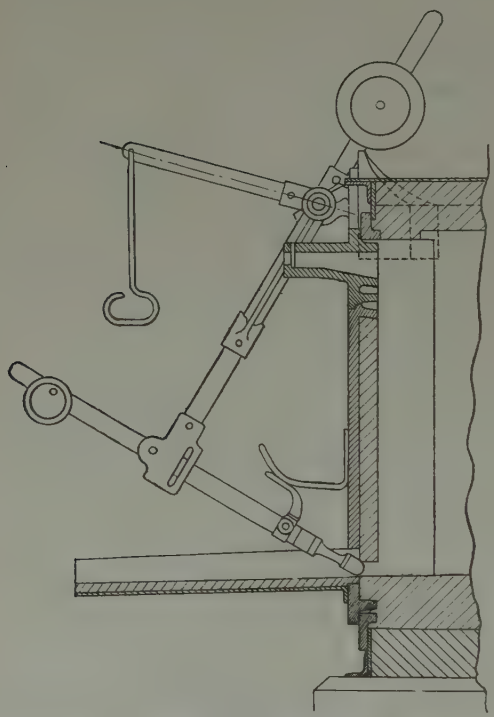


FIG. 37—MECHANICALLY OPERATED LEVER FOR STOPPING THE STREAM IN THE TAP HOLE

has been designed and operated in Germany. The method of operation is clearly evident from the illustration. It is claimed that when this device is handled properly, the tap hole is closed simply by pulling a lever, and is re-opened to let the iron out by releasing the same lever. The plug comes out smoothly and the plug and plug-hole last for weeks without renewal. The cast iron plug has a taper slot at one end for fixing on the lever, and a large pitch thread at the other end for holding the refrac-

tory composition which acts as the plug for the tap hole. The best plug composition is supplied by the makers of the apparatus.

A simple piece of apparatus for regulating the quantities of alloy additions to the stream of iron in the spout consists of a sheet metal funnel with an opening ½ to ¾-inch diameter in

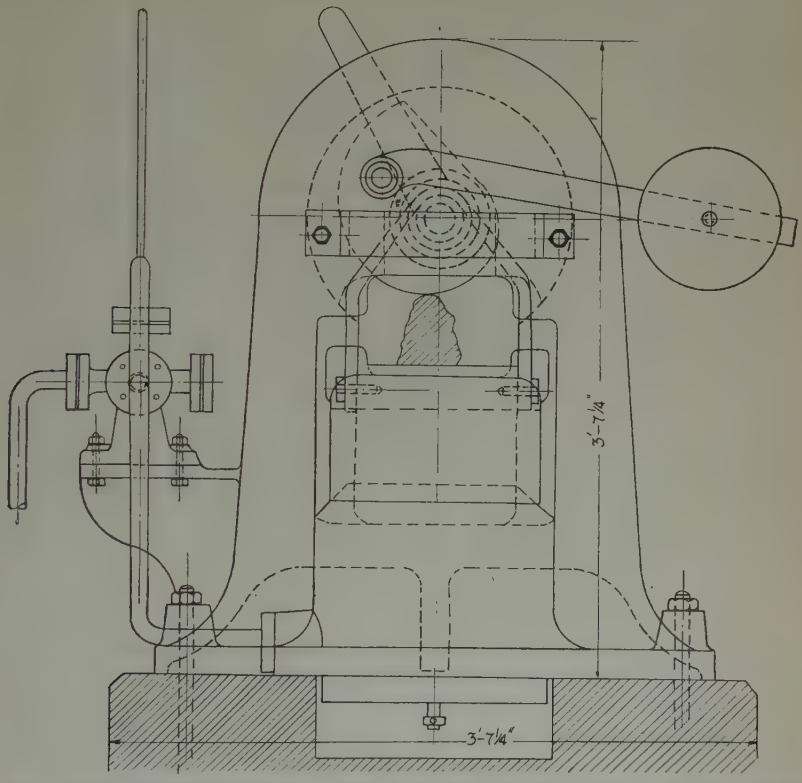


FIG. 38 -A HYDRAULICALLY OPERATED MACHINE IS UTILIZED IN SOME PLACES FOR BREAKING PIG IRON

the apex. This device is suspended from a suitable support and the flow of the contents is regulated by a metal rod or plunger directed by lever and guide into the opening. With this device a weighed quantity of ferroalloy, nickel or other material may be added gradually to the stream of iron as it flows underneath and toward the ladle. The funnel should be mounted approximately

15 inches above the stream to impart sufficient force and speed to the descending material to penetrate the stream of molten iron.

Where slag is handled in large volume, some form of slag ladle is used to facilitate the transport of this material. The simplest is a cast-iron bowl, mounted on trunnions and carried on a bogie frame. The bowl usually is in a truncated, pyramid form, with the wide end uppermost and all corners of substantial radius. Usually the cast iron bowl is unlined except with a coating of claywash or blackwash. Cold slag readily is dumped from this type of ladle. In some places a substantial steel eyebolt, with a long shank is imbedded in the slag as collected. By this means, the mass of cold slag can be handled by a crane. Ladle bowls, trunnions, bogies and frames of slag ladles, invariably receive rough handling. For this reason any endeavor to save weight of material in their construction is false economy.

Pig breaking machines occupy a place in the list of auxiliary cupola plant. Pig breakers operate by direct belt or electric motor drive, or from the hydraulic power service. The electrically driven type readily is adaptable as a portable machine. A simple hydraulic type machine is illustrated in Fig. 38. Pig breaking by machinery in the general foundry is not so common as one might expect. Machine cast pig iron has rendered it practically unnecessary. It is alleged generally that the act of lifting the individual pigs to the table of the breaking machine, is practically as arduous a task as breaking by sledge hammer. In the adoption of machine breaking, the design of the machine and its location in respect to the stock yard, the stock yard handling mechanism and the cupola charging arrangements require careful study.

Weighing equipment is by far the most important item in the list of auxiliary cupola plant. Construction of weighing machines is in the hands of firms specializing in this class of machinery, and the foundryman today has available an almost unlimited choice of simple and automatic weighing machines, platform, beam, suspended type, direct reading and automatic. It is hardly necessary to deal with this feature in detail.

OPERATION

Beyond dispute, accurate weighing of the components of the cupola charge, is fundamental in obtaining uniform quality of molten metal. Likewise beyond dispute, weighing of the coke charges is the only method of exercising strict control over cupola economy. In view of the importance attached by every foundryman to fuel economy in the cupola, it is surprising to find the large number of plants still remaining where the coke charges are not weighed. Weighing the coke charges results in greater fuel economy than is secured by many of the fanciful devices proposed for this purpose.

Character of the cupola plant necessitates a good solid foundation which usually takes the form of a substantial concrete bed resting on the gravel into which the columns are bolted by substantial long bolts with large washers. Usually the four columns are tied together, either by a cast iron foundation plate or steel angle irons and cross bracing, which in all cases should be covered by a 3-inch layer of good concrete. The cupola shell erected on these columns should be free from all staging to allow perfectly free expansion. Where inclined charging devices are attached to the cupola, it is a good plan to allow some freedom in the attachment for this same purpose. The cupola foundation and the foundation of the inclined charging machine should be carried on a continuous reinforced concrete foundation or raft, and a similar form of reinforced concrete raft foundation is advisable in all cases where the solid character of the earth foundation is suspected.

The cupola shell generally is supplied either painted with red oxide paint, or with one of the bitumen base paints now available. It is a good plan to allow this first coat of paint, also the mill bloom on the steel plates, to disappear by the combined action of heat and atmospheric weathering, before repainting. The shell should be well scaled before repainting, and should be repainted every twelve months.

CHAPTER IV

Charging

Early charging methods—Complete mechanical charging—Raising the material to the charging floor—Mechanical charging—Complete mechanical handling and charging—Electromagnets.

METHODS of handling and charging materials into shaft-furnaces have occupied the attention of furnace engineers from time immemorial. In earliest times, the problem of charging was solved by the choice of a site, in which the shaft furnace was located on a hillside, where the material could be collected and stored on the higher level and charged direct by hand labor into the furnace. Simplicity of this arrangement can be maintained on any site by lowering the cupola below the ground level in such a manner that the charging door is in a line with the ground level. Such an arrangement described within comparatively recent years is diagrammatically illustrated in Fig. 39.

Mechanical methods for raising the materials to the higher level of the charging hole commonly were preferred to an arrangement as in Fig. 39. In present days of large unit foundries and high labor charges, increasing attention is paid to the problem of mechanical handling of materials in all departments of the foundry with the object of conserving both time and labor. Mechanical handling of materials to the cupola has received its full share of attention. Simple mechanical methods of the early days have had to be elaborated extensively. Vast ingenuity has been displayed by engineers and foundrymen in this direction, to meet the many and various requirements of modern foundry practice.

A work of this nature cannot describe all the apparatus, combinations of apparatus and arrangements that have been designed for cupola charging purposes. No one type or arrangement possesses the quality of universal utility under the wide variety of existing conditions. Method of cupola charging, and consequently the type and arrangement of the charging apparatus is connected intimately with the layout of the cupola plant, in re-

lation to the foundry floor and stock yard; degree of accuracy of control necessary over all the various components of the charge; labor costs and other local conditions.

Charging a foundry cupola can be divided under three principal headings as follows: 1—Collecting the requisite quantities

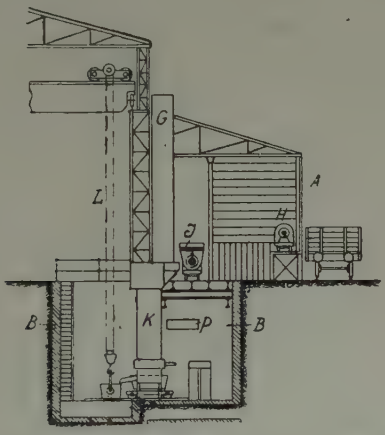


FIG. 39—CUPOLA ARRANGED FOR GROUND LEVEL CHARGING

of the components of the charge; 2—raising this collected material to the charging door level; 3—charging this material into the cupola shaft.

Complete mechanical charging involves the use of mechanical equipment for performing all these three operations. Degree of completeness depends upon how far these operations are performed by mechanical means.

Foundrymen generally are interested specially in the mechanical performance of the third item, charging the material into the cupola. They consider, and rightly so, that to obtain the best results in the working of the cupola, and in the character and quality of the melted mixture great care should be taken in the distribution of the charge. Opinion still is held by many foundrymen that this operation is performed best by hand methods. Necessity for regular and uniform distribution of the charge is common to all shaft furnaces. In modern blast furnaces, care-

fully designed and elaborate arrangements of mechanical methods, involving double bells and rotating distributors, have been evolved to ensure this regularity and uniformity. So far it has not been

FIG. 40—TILTING BUCKET AND TRAVELING HOIST ARE APPLIED TO CHARGING THE CUPOLA

found necessary or possible, to introduce blast furnace methods into cupola charging practice.

In considering this question of mechanical charging *versus* hand charging, it is necessary to maintain a correct sense of proportion. Relation between normal size of materials used and vol-

ume of the respective charges in small cupolas is such that little difference will be found in the regularity and uniformity of the charges, fed in small quantities by hand, or charged in larger

FIG. 41—AN ELECTRIC MOTOR IS EMPLOYED TO HOIST THE BUCKET WHICH RETURNS BY GRAVITY UNDER BRAKE CONTROL

volumes mechanically. As the diameters are increased in proportion to the size of the materials charged, the danger of irregularity in the charging increases. Tendency is to charge into the center and to neglect the edges. Modern devices are designed to take this into consideration. Irregularity in charging is by no

means greater than occurs in hand charging in the absence of constant labor supervision.

During recent years mechanical methods of charging have developed extensively beyond the stage of lifting the material to the charging level. Following the natural line of development of

FIG. 42—CHARGES ARE MADE UP IN SPECIAL TIPPING CARS AND CONVEYED TO THE CHARGING DOOR ON A TRANSFER CAR

complete mechanical charging, these methods of lifting in the first place will be reviewed briefly.

Probably the simplest form of lifting device is the hand-operated jib crane, still to be found in some of the small old-fashioned cupola plants. The crane was erected on a staging around the cupola, at or about the charging level. The charges, assembled in skips or on trays, were hoisted to this level by the swinging arm and deposited on the stage, from whence they were charged into the furnace by hand. A large scale development of

this method of raising the material to the charging level still is in efficient operation in several foundries.

In one large installation, a mechanically-operated crane with an 80-foot jib is arranged to sweep the stock yard and to raise the material on flat trays to the charging level of the cupola. This arrangement is comparatively simple, but it has a number of defects which are overcome by other apparatus of an equally simple nature. The arrangement does not lend itself to a con-

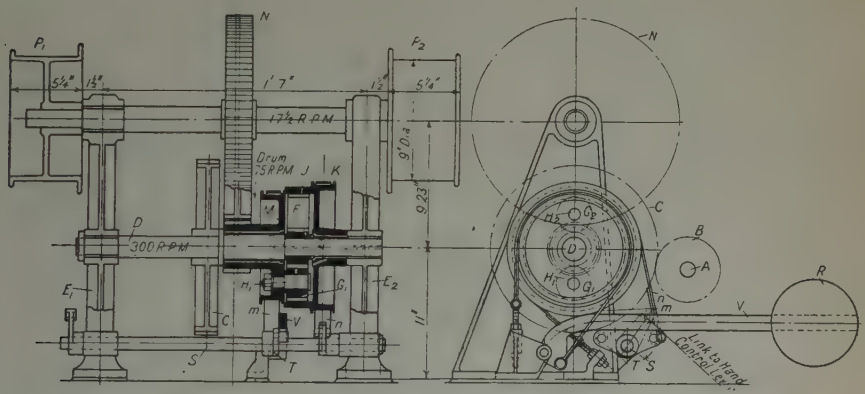


FIG. 43—SECTIONAL SIDE ELEVATION AND END VIEW OF POWER DRIVEN HOISTING MECHANISM

venient layout of the stock yard. The stocking area is limited to the maximum radii of the crane. Also the crane does not operate economically over all the area. It is slow in operation and places too much reliance on the continued judgment of the operator.

The cage hoist constitutes the most common device for raising material to the charging level. The material is loaded at ground level in barrows, or trucks, which are hoisted in the cage to the charging level. All forms of power, including steam, electric, hydraulic and pneumatic, have been adopted for operating such hoists. Electrically-operated lifts probably are most common today. A common type of electric hoist is that in which the cage is lifted by a rope passing over a grooved drum, erected on top of the well shaft. The shaft frame is constructed of steel with four well-seasoned pine wood guides bolted to the corners

of the steel tower. The two back guides usually are grooved to receive the balance weight. Generally a corrugated sheeting roof is supplied to house the winch and motor at the top of the shaft. The cage is balanced and the winch is operated by a suitable motor at a hoisting speed of about 80 feet per minute. Push botton control can be arranged on the lift itself, or on the landings. Safety gear, automatic stops to prevent the car traveling beyond the landings, mechanical and electrical braking generally are provided to ensure complete control of the lift. Usually the lift cage is provided with narrow gage track rails registering with

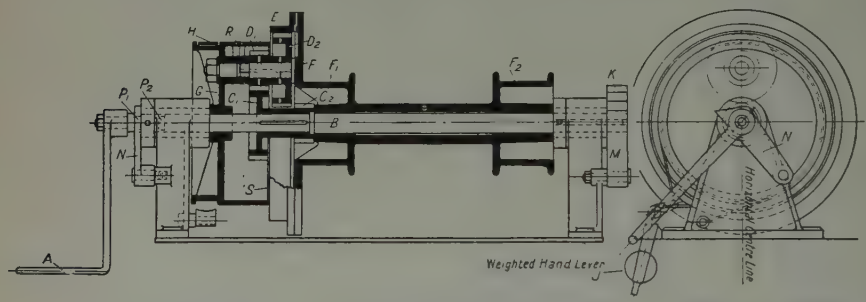


FIG. 44—ARRANGEMENT OF HOISTING GEAR FOR HAND OPERATED MACHINE

the track serving the stock yard. Wheeled trucks may be run direct from the stock yard to the lift. With similar rails on the staging the material easily can be led direct to the cupola charging door.

Use of a cage lift or hoist in its simplest form relies on assembling charges in the stock yard and delivery of these from the charging platform into the furnace by manual labor. In many of the larger plants efficient layouts have been designed around the simple hoist as the main lifting appliance. The staging is provided with a number of lines of track to receive special tipping bogies delivered from the hoist to the tracks by a transfer car and which then are tipped into the charging hole of the cupola from a second transfer car. With a sufficient supply of trucks this arrangement presents an efficient application of the vertical cage hoist to cupola charging shown in Fig. 42.

In many instances the hoist is used solely for raising mate-

rials from the main stock yard to the charging stage level. A secondary stock of material is maintained on the stage which is equipped with a weighing machine. Charges are made up and

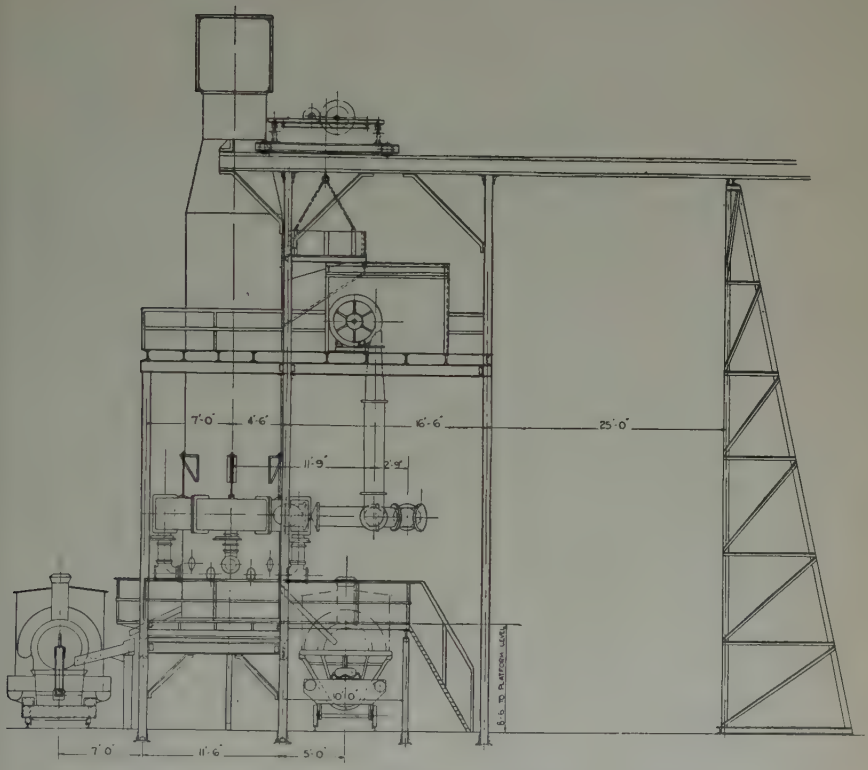


FIG. 45—THE BACK OF THE CHARGING PAN RESTS ON THE EDGE OF THE CHUTE. WHEN THE HOIST COMES DOWN THE PAN TIPS AND DISCHARGES THE LOAD INTO THE CUPOLA

thrown into the furnace by hand, directly from the stage. Pig iron is broken into suitable sizes in the stock yard before delivery to the stage.

The simple inclined hoist and car for carrying barrows or trucks of material to the stage level, similar in design to that frequently used in the older methods of charging blast furnaces does not appear to have been adopted in cupola charging.

In many of the cupola plants where large quantities of material are handled, the overhead crane traveling on parallel gantries is adopted. Charges can be made up at the ground level and raised in suitable skips or trays to the charging level, or, a secondary stock can be maintained on the staging from which the charges are made up and charged directly into the furnace. Advantage of this method is that the crane gantries can be extended more or less indefinitely to cover a large range of stock yard. The stock yard can be arranged readily parallel to the railroad tracks and the services of the traveling crane can be requisitioned for unloading the cars of incoming material and storing it in the yard.

FIG. 46—MECHANICAL CHARGING EQUIPMENT WITH MONORAIL RUNNING IN A STRAIGHT LINE OVER THE STORAGE YARD

Mechanical charging systems may be defined as arrangements embodying both raising of material from the ground level, and charging it direct into the cupola without intervention of hand labor. At present practically every large cupola plant utilizes some form of direct mechanical charging, and the tendency even in small plants is to eliminate manual labor on the stage. An outstanding advantage in many of the smaller mechanical charging devices is the elimination of the staging, frequently an item of considerable capital expenditure.

Quite a wide variety of mechanical charging devices have been designed. Apart from detailed mechanical variations they can be classified as either one or the other, or combination of two classes, according to whether the material is tilted into the cupola

from skips or buckets, or use is made of a form of drop bottom bucket.

In the simplest method of mechanical skip charging the skip charged with material is lowered on to the edge of chute, extending round the charging door. This layout is illustrated in Fig. 45, also in Fig. 40. which shows the design of a skip and chute as used on a 3-ton per hour cupola, working with individual 500-pound metal charges. With a full load the skip remains in the horizontal position by stops bearing against a yoke. A stop is provided in front and on lowering the skip on to the cross member of the chute, the skip automatically tips the charge into the chute.

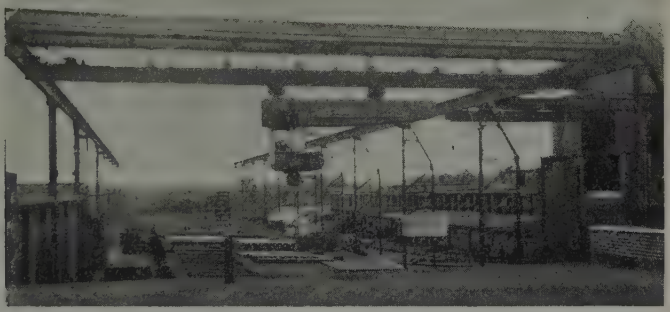


FIG. 47—THE CHARGING CAB OPERATES OVER A TROLLEY TYPE I-BEAM CRANE

A simple arrangement for two cupolas utilizing a traveling pulley block for lifting and lowering the skip, is illustrated in Fig. 40. The skip is shown in the tilted position. The hoist is of the traveling pulley block type, with electrical raising and traveling motions. When operated with direct current the controls can be mounted readily at ground level. Use of an indicating device insures accurate location of the skip over the respective chutes. The arrangement illustrated utilizes a bucket with a metal capacity of 500 pounds and of robust construction with renewable wearing strips. The chute itself is provided with a renewable mild steel wearing plate and sill. Installation of this arrangement is low in first cost, and maintenance and upkeep are small.

Where such an arrangement is operated from the ground level, and the bucket is out of sight of the operator, an indicating device readily can be arranged by a wire passing over suitable pulleys. Exact locating also can be provided electrically by suitable contactor gear and dynamic braking. This system of me-

FIG. 48—CUPOLAS AND CHARGING MECHANISM IN AN ENGLISH FOUNDRY

chanical charging can be modified by the adoption of various types of lifting gear which, of course, increases the cost of the installation considerably.

A simpler arrangement still is a chain and bucket type elevator. All staging is eliminated definitely and the buckets discharge into a suitable single or double chute serving one or two cupolas.

A chain and bucket elevator utilizing a single bucket, is illustrated in Fig. 41. This machine is made in three sizes, with bucket capacities of approximately 3¼, 7 and 16 cubic feet respectively. Method of operation is clearly visible from the illustration. To obviate the use of a reversing motor an ingenious adaptation of a continuously running motor has been devised. All

the motions of the bucket are controlled by one lever. Return of the bucket is effected by gravity under the control of a brake operated by a hand control lever within reach of the operator. If the hand lever is released, the bucket automatically is brought to rest easily at the bottom of the elevator.

The hand-operated charging machine designed for use with

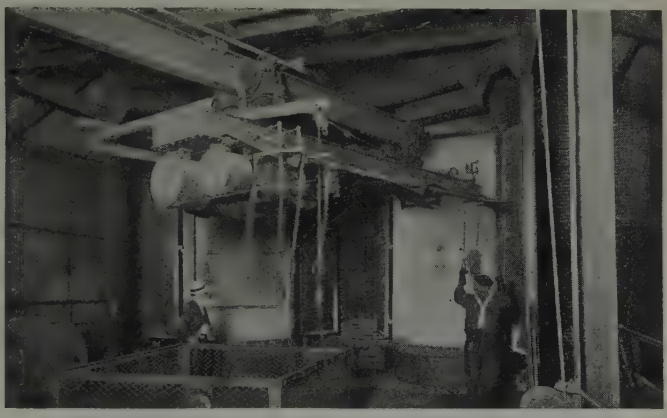


FIG. 49—FLOOR OPERATED TYPE CHARGING CRANE

dwarf cupolas or cupolets does away with the necessity of a staging. The cupola may be charged and manipulated by one man. The bucket mounted on two wheels is provided with small projections on either side, which engage a series of pins fixed near the top of the framework and tip the bucket, its contents falling into the cupola. The patented hoisting gear is designed for two lifting speeds, one for coke and the other for iron charges. It has a nonreversing crank handle and the empty bucket returns by gravity.

The side dump charging machine shown in Fig. 52, designed and manufactured by the Whiting Corp., Harvey, Ill., facilitates charging material into the cupola. It involves the use of trucks conveniently designed to be locked in position on the table of a pneumatically or hydraulically operated tilting machine. This is essentially a charging machine without any lifting and lowering devices and finds extensive use in many American foundries operating on large tonnages. With a suitable arrangement of the

cupola stage where the trucks can be transferred readily to the tilting platform, exceptionally economical results are obtained. Special attention is directed to the chain doors, operated pneumatically.

An extremely simple and ingenious hand operated balanced charging machine also has been designed by the same firm. This is a cast iron distributing block attached to the end of a steel beam, supported at the center by a pin, and counterbalanced so that it can be moved easily into and out of the cupola by hand. The charges of iron and coke are carried separately in balanced

FIG. 50—CAB OPERATED CRANE AND A SPECIAL TYPE OF CHARGING BUCKET

cars equipped with roller bearings. These cars with full load may be turned easily by one man. No turntables are required, the curved angles on the floor act as guides easily locating the car relative to the charging floor of the cupola. A steel charging floor is required.

The *modus operandi* is clear from the illustration Fig. 53 which shows the charger installed on a cupola lined to 45 inches inside diameter. It is claimed that this charger secures uniform distribution of the charge and that it is applicable to old and new cupolas. It is recommended for any cupola over 45 inches inside diameter. Location of the distributing block with respect to the cupola is adjustable by moving the tilting beam horizontally in

and out of the cupola if a change in distribution of the charge is found necessary. Later development of this idea now is available.

The primary object in the use of drop bottom buckets is to insure regular distribution of the charges, a difficult feature in large cupolas with side tipping buckets and charging chutes.

Drop bottom buckets vary in the mechanism for opening the bottom doors, but all buckets are designed a few inches less than the diameter of the cupola lining. They enter the cupola where the contents are discharged en-bloc. If the bucket is charged

FIG. 51 -CHARGING BUCKET WHICH HAS THE BOTTOM HINGED AT THE CENTER

regularly, the charge will be deposited properly in the cupola. Difficulty of insuring regularity in charging is more apparent in large than in small diameter cupolas.

One of the simplest types of drop bottom bucket, illustrated in Fig. 51 by courtesy of the Shepard Electric Crane & Hoist Co., Montour Falls, N. Y., is a cylindrical mild steel shell with riveted stiffening bands at the top and bottom and provided with a suitable hook for attachment to the crane. The bottom of the bucket is closed by two semicircular flap doors hinged to a diametrically disposed rod and locked by the lever controlled latch,

clearly shown in the illustration. The levers controlling the latches are operated by a yoke type operating lever surrounding the bucket, which in its turn is operated by a wire rope from the cab of the crane type charger or any other convenient place. In operation, the full bucket with the doors latched is placed inside the cupola by the crane. The bottom doors are unlatched and released by a pull on the latch release cable, and the charge is deposited in the cupola. The bucket then is withdrawn and the bottom doors either reclosed by hand or by simply lowering until the bucket rests on the charging floor.

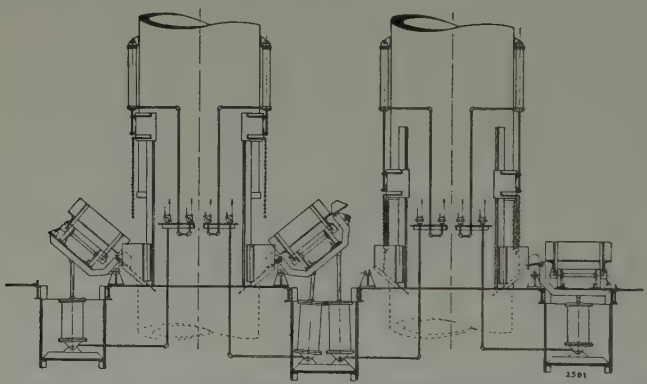


FIG. 52—CUPOLAS MAY BE SERVED BY A DUPLEX MACHINE IN THE CENTER OR BY A SINGLE MACHINE ON THE OUTSIDE

Another type of bucket, illustrated in Fig. 50 by courtesy of the same firm, is described as the umbrella type. The object of this type of bucket is to obtain better distribution of the charge toward the center of the cupola.

A slightly modified form of the former type of drop bottom bucket is illustrated in Fig. 55. The two semi-circular hinged doors are operated by four levers *D* and *E* attached to two specially formed links *N* arranged to move vertically in the slides *P*. The doors are held closed by wire ropes attached to the links *N* and controlled from the operating platform. This type of bucket is used with the charging arrangement illustrated in Fig. 49.

An ingenious form of collapsing bucket which automatically opens when lowered into position is illustrated in Figs. 54 and

57 by the courtesy of Cochrane & Co. Ltd., Middlesbro, England. In the application of this bucket the top of the cupola is equipped with cast iron curved bearer rails as indicated in Fig. 54, which also clearly shows the form of the bucket and the manner in which it opens by weight of the material contained. The loaded bucket is raised and lowered in the manner diagrammatically indicated in Fig. 54 and the charge automatically is deposited in the cupola. A loose link to prevent collapse is used when loading the bucket at ground level. The link is removed immediately after the loaded bucket is suspended on the crane.

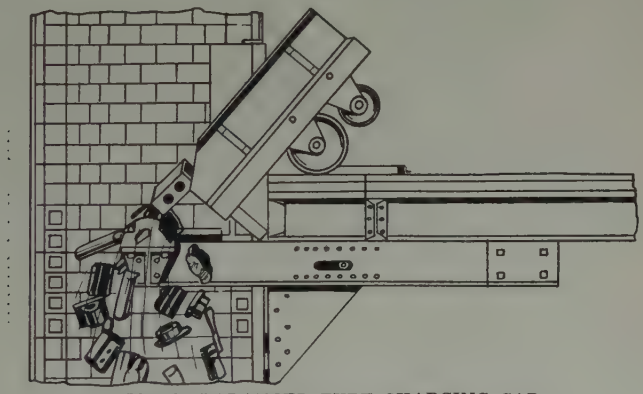


FIG. 53—BALANCED TYPE CHARGING CAR

Drop bottom buckets can be filled with the correct charge at the ground level. Various types of special purpose cranes are available to hoist the bucket from the ground level, bring it into position in the cupola and drop the bottom for discharging. A typical example is shown in the illustration Fig. 50. This is based on standard cage controlled monorail hoists, in which a front trolley is attached to the structural frame in such a manner that the snout of the hoist projects into the cupola.

A similar arrangement adapted for ground level control is illustrated in Fig. 49, which also illustrates an ingenious arrangement for charging two cupolas with the same charging hoist. In this arrangement the I-beam monorail is pivoted in the center and suspended by trolleys from two curved segments.

The charging hoist may be directed toward either of the two cupolas.

Drop bottom buckets also are utilized with a chute extension to the charging door. A convenient arrangement of a removable chute can be adopted where a substantial charging platform is in existence. The chute is mounted on a four-wheeled

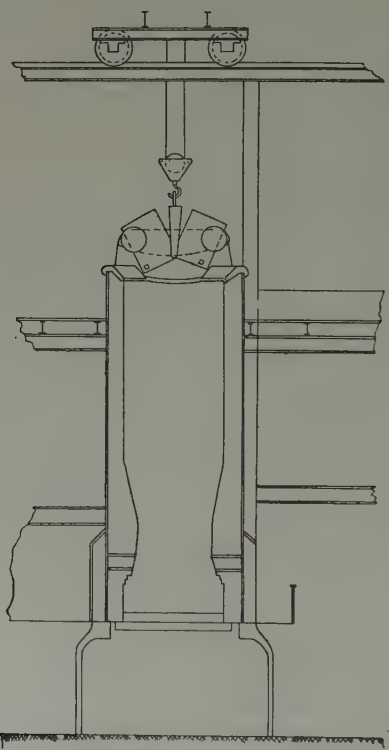


FIG. 54—SKIPS OPEN AUTOMATICALLY WHEN WEIGHT RESTS ON BEAMS

bogie maintained in position at the charging door by hooks attached to the side of the cupola.

Individual needs and layout of a particular foundry constitute the most prominent consideration, and it will suffice in this connection to describe and illustrate several typical systems.

In many places, the stock yard is served suitably by a

monorail system leading to the cupola. This system necessitates placing the monorail at a height that in some instances may prove inconvenient, unless the monorail is used in conjunction with an electric hoist. Charging buckets are filled direct from the stock yard and each charging bucket is suspended from an automatic scale which constantly indicates the load. Full buckets

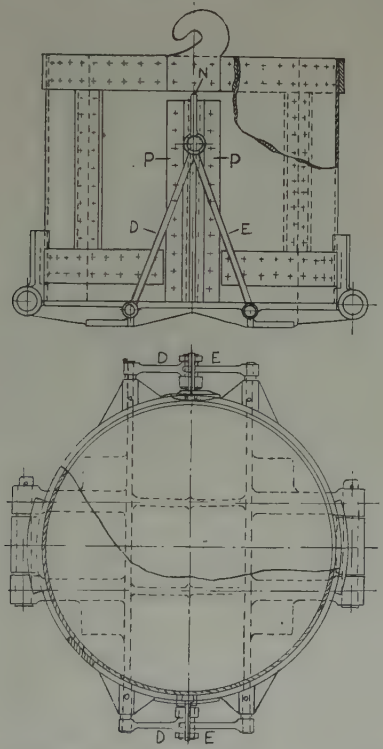


FIG. 55—PLAN AND ELEVATION OF DROP BOTTOM BUCKET

on the monorail are led to elevators and raised to the charging level where the contents are dumped into the cupola by hand.

One application of the Rein inclined runway is illustrated diagrammatically in Fig. 56. The horizontal monorail serving the stock yard has a small piece of rail suspended from the inclined monorail and operated by the cable and winch. The crane is brought to rest at the end of the horizontal monorail,

suspended on the small piece of rail which in turn is suspended from a crab on the inclined monorail. This is disconnected and pulled up the inclined rail. Arriving at the top, the small piece of rail locates in a space in the runway, thus enabling the bucket to be moved along.

The ends of runways are arranged to close automatically; thus preventing all accidents. Power required by the winch is extremely small, as half the load is counterbalanced.

A cage controlled hoist of the type described obviates the difficulties arising from the height of the monorail. The stock

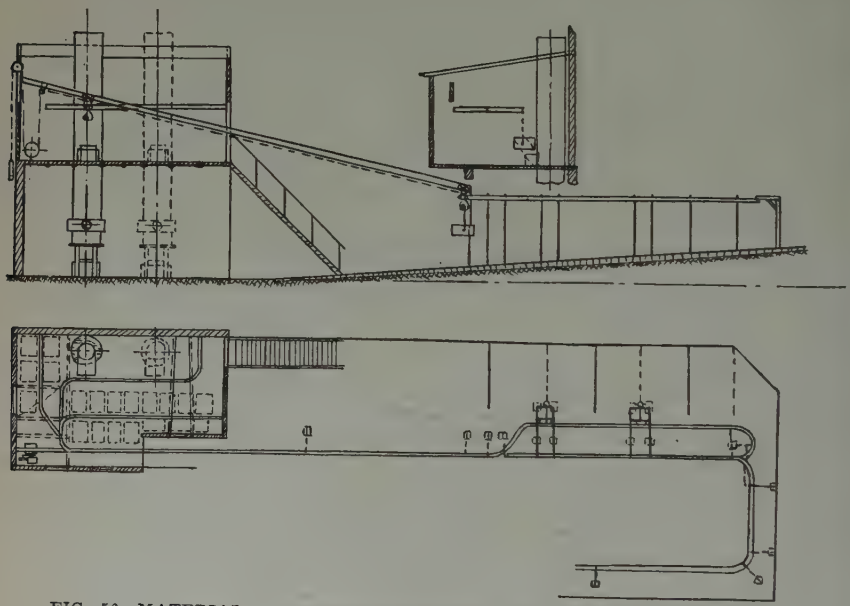


FIG. 56—MATERIAL IS CARRIED ALOFT ON AN INCLINED MONORAIL

yard can be covered by a monorail hoist in conjunction with a transfer crane as shown in the two illustrations, Figs. 46 and 47.

This system is of considerable interest. Incoming pig iron and scrap may be unloaded by magnet attachment. An electrically operated grab bucket may be utilized for handling molding sand and other loose materials. The transfer crane is of the traveling crane type equipped with motor and traveling

gear operating on gantries covering the stockyard. The transfer crane carries an I-beam which may be brought in line with the I-beam monorail track to the cupola. This equipment affords almost complete control over handling of raw materials and has found extensive application in many foundries.

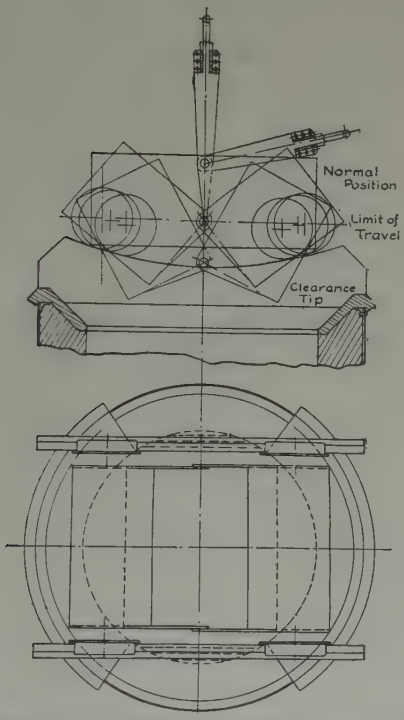


FIG. 57—GENERAL ARRANGEMENT OF CUPOLA CHARGING SKIP

Part of the complete mechanical charging plant on the four cupolas which supply molten metal to the "spun" pipe plant of the Stanton Ironworks Co. Ltd., England, is illustrated in Fig. 48. This plant is operated in conjunction with a specially designed bunker storage with a capacity of 750 tons iron, 120 tons coke, and 45 tons limestone, approximately two days' supply. A scale transfer car collects the charge in drop bottom buckets referred to previously, which are transferred to the inclined charging hoists as shown in the illustration.

Electric magnets cannot be used readily for direct cupola charging, but they find extensive use in large plants, unloading pig iron and scrap consignments. Original application of electromagnets, about a century ago, for lifting materials is attrib-

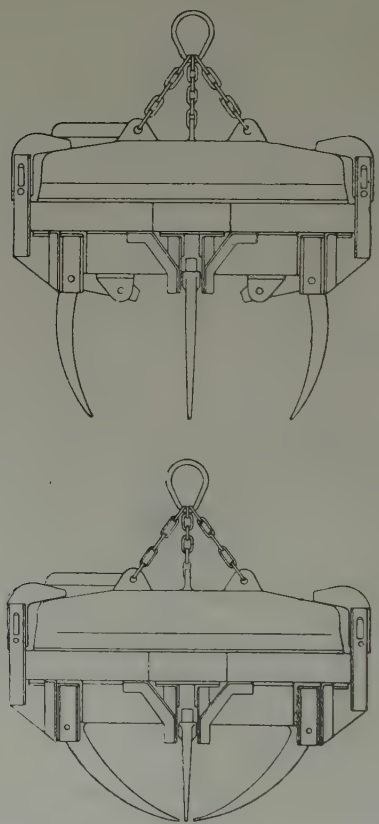


FIG. 58—MAGNET WITH GRAB ATTACHMENT FOR HANDLING LOOSE SCRAP—OPEN AND CLOSED

uted to Arago in France, and to Sir William Sturgeon in England. Their industrial use appears to have been adopted extensively first in the United States about 30 years ago. Since that time their use has extended rapidly.

Three types of electric lifting magnets have been evolved:

(1) The circular type magnet for handling loose material. (2) The rectangular type for handling sheets and plates. (3) The bipolar magnet for handling material with regular sections and billets.

We are principally concerned with the circular type magnet for handling loose pig iron. The circular type magnet, employed for handling pig iron and scrap, consists of a shell casting of high permeability steel, machined inside to receive the energizing coil and fitted with lugs on the top for suspension purposes. The coil, usually of copper tape, is carefully designed and special precautions are taken with the insulation. Leads are brought from the energizing coil to a terminal box to which the external leads are connected. Magnets generally are controlled by a drum type controller, similar to the ordinary street car pattern, or operated by automatic contractors controlled by a master switch. Robust switchgear always is desirable and suitable resistances are provided to absorb the induced current on breaking the circuit and for regulating the lifting power. A demagnetizing arrangements is provided to ensure instantaneous release of the load.

Magnets operate on direct current circuits and where alternating current only is installed a motor generator set becomes necessary. Various devices are adopted for taking up the cable slack on the magnet. Usually it is taken up on a winding drum operated by a separate motor or driven from the main crane gearing. Alternately a series of compensating pulley and weights are used.

Lifting power of a magnet depends on the nature of the material lifted. With a solid load, a magnet will lift from 5 to 15 times its own weight, depending on the size of the magnet. For example, a 26-inch diameter magnet, weighing 600 pounds, will lift a block of steel weighing 5 tons and a 66-inch diameter magnet, weighing 3 tons, will lift a block weighing 15 tons. When handling light scrap, the load lifted is greatly reduced, coming down to about 150 and 1200 pounds, respectively, in the examples quoted.

Advantage in using electromagnets makes itself apparent

in the speed at which the material can be handled, due to the saving in time while attaching and detaching the load. The lifting power can be increased when handling loose scrap material by the use of the gripping attachments illustrated in Fig. 58. A good craneman on a fast crane and assisted by a ground man can unload pig iron at the rate of 60 tons per hour. The electromagnet finds a useful sphere of operation in the foundry breaking scrap material. A spherical skull cracker is used, so that no matter how it falls, it can be picked up readily by the magnet. A 66-inch diameter magnet will lift a ball weighing 8 tons.

Modern magnets do not require any reserve power supply to cover the commercial variations in voltage. However, men should be prevented from walking underneath loaded magnets. The current might fail, thus immediately releasing the load. Good practice favors wiring magnets from the main circuit, or a single circuit, to obviate danger of the circuit breaking from causes arising out of the operation of other machinery on the same circuit.

CHAPTER V

Receivers

Distributing molten metal—Reservoir ladles, receivers and forehearths—Ardelt receiver—Matchell type receiver and modifications—Whiting oil fired receiver—Hurst oil fired receiver—Desulphurization of cast iron—Duplex process—Walter, Durkopp, Luyken, Rein processes—The shaking or jolting forehearth—General notes on receivers.

VARIOUS mechanical handling and distribution systems have been devised with the object of expediting operation and lightening the manual labor burden involved in transferring molten metal from the cupola to the molds. Factors governing the design of these systems are too remote from the subject to be considered in this work. However, generally speaking, many of these systems are concerned intimately with the rate of metal melting and the manner in which it is stored. A description of the plant adopted for this purpose is highly desirable.

Various special forms of apparatus devised for this purpose are known as receivers, receiver ladles or forehearths. Storage of the molten metal in the standard cupola is effected in the space below the lowest tuyeres or the slag notch and known as the well or hearth of the cupola. Molten metal is collected and stored in contact with the coke forming the bed, and obviously the storage capacity is limited by the coke present and the limiting dimensions of the well itself.

In many foundries, the well of the cupola is too small to supply metal in the most expeditious manner. Where the work varies and the quantity of metal demanded from the cupola from time to time varies within wide limits the collecting capacity of the cupola usually is augmented by a ladle in front of the tapping spout. Large quantities of metal required for the heavier castings can be collected over a period of time without interrupting the casting of smaller items for which metal can be withdrawn as desired from this ladle.

A ladle used in this manner is described as a receiver ladle,

and is the elemental form of all the more or less elaborate receivers or forehearths at present in use. Initial purpose of the reservoir is to smooth the difficulties of an irregular demand of molten metal from what might be considered a uniform or uniformly varying source of supply. Many other facilities of use in special cases were found to accompany the use of receivers. As a result many special types of receivers have been designed in which one or several of the special facilities have been emphasized.

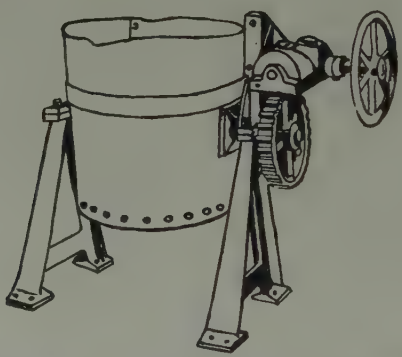


FIG. 59—RESERVOIR LADLE WITH HAND TIPPING GEAR

Apart from its use as a reservoir, the receiver collects and stores the metal free from contact with the coke. This is an important feature where precautions are taken to prevent molten metal from picking up carbon by absorption. With the receiver, the melting practice may be adjusted to collect charges of definite composition before casting, also it facilitates addition of special alloys where necessary or desirable. Obviously features readily may be incorporated for effectively skimming or separating molten metal from the slag, something highly desirable where certain special additions are to be made to the metal. In many receivers these special facilities have occupied a prominent place in determining the features of the design.

The reservoir ladle probably is the simplest form of receiver. A standard type ladle mounted on trunnions and provided with hand or power operated tilting gear. Typical illus-

trations of reservoir ladles are shown in Figs. 59 and 66. These ladles, in common with other receivers, generally are built in capacity from half to three-quarters of the hourly melting capacity of the cupola. They are manufactured in capacities varying from 1000 to 20,000 pounds. The lip or spout of the ladle in the form of a circular orifice clearly illustrated in Fig. 66 serves to

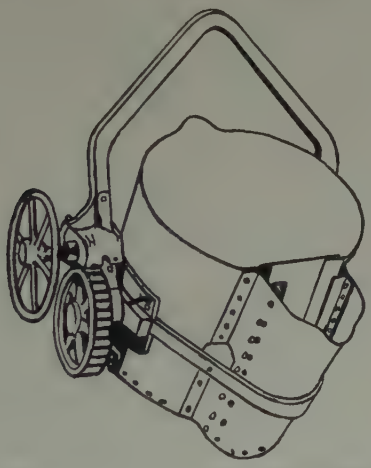


FIG. 60—TEAPOT SPOUT LADLE WITH SPOUT OUTSIDE

some extent to partially skim the metal delivered to the foundry ladle.

Reservoir ladles of the teapot spout type are in use in this country, the continent and America. One of these ladles in elliptical form constructed by the Whiting Corp. is illustrated in Fig. 65. It is made in approximately 1½, 3, 5 and 8 tons capacity. Manner in which this type of spout delivers metal free from slag is shown in the illustration. Detail of constructing the teapot spout in ganister is illustrated in Fig. 61.

The early standard type of receiver or forehearth was a circular brick lined chamber erected on a solid foundation and directly connected to the cupola tap hole. A common type in use for many years is shown in the illustration Fig. 62. The receiver is fitted with metal and slag spout. A peep hole is in line with the cupola connection and a vent pipe is shown in the roof.

The vent pipe formerly was arranged to lead back into the cupola at a point about 3 feet above the level of the tuyeres, and still is extensively used in this manner. It is claimed that the metal is maintained uniformly hot in a receiver of this type totally enclosed, with the hot blast from the cupola circulating over the surface of the molten metal collected therein. Obviously, the loss in temperature which must accompany the use of an open

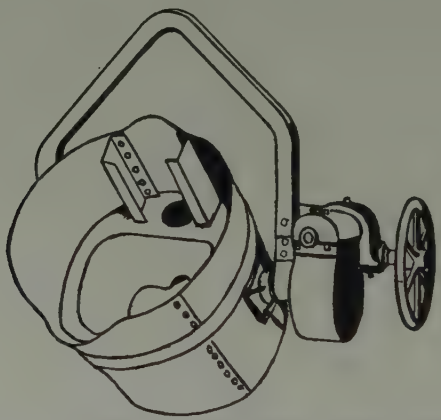


FIG. 61—ELLIPTICAL LADLE WITH SPOUT INSIDE

reservoir ladle is avoided. In smaller units, where the receiver is used principally for a reservoir, the totally enclosed receiver of this type is to be preferred. Receivers or forehearths of this type reduce the amount of coke necessary for the bed. The well space below the tuyeres can be reduced to an absolute minimum, sufficient only to allow the construction of the connecting passage to the receiver.

A comparatively recent modification incorporating some useful improvements in the design of this type of receiver has been designed by Ardelt in Germany. The receiver is illustrated in Fig. 64.

Bottom of the new receiver—apart from a useful slope toward the tapping hole—is on a level with that of the cupola. The liquid iron passes through an opening from the hearth of the furnace, and into the receiver at the same level. Slag floats on top of the iron in the melting furnace, and, therefore, cannot

reach the receiver. A slag-free iron results. As more and more slag is collected in the melting furnace, it is passed off through a slag notch in the usual manner, or is collected by the slag syphon system. Desulphurization can be brought about in the receiver so long as the upper connection between receiver and furnace remains closed. The iron bath in the receiver can be heated

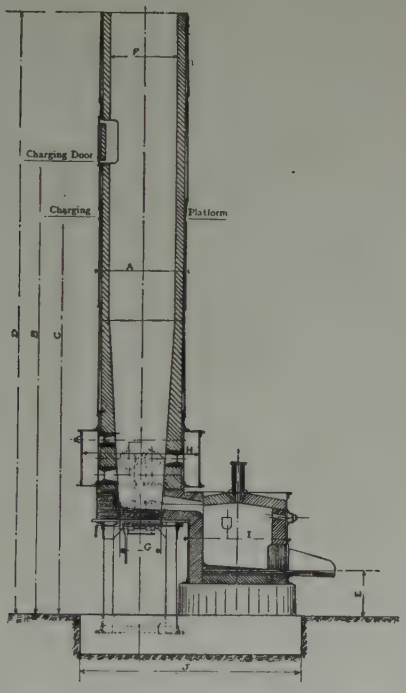


FIG. 62—EARLY TYPE OF RECEIVER BUILT ON A SOLID FOUNDATION

by oil, coal dust, gas, coal, coke, or other fuel.

The Ardelt system illustrated in Fig. 64 shows the usual construction of a furnace shaft. At point 2 the air enters the blast belt 3, and out of this through the tuyere 4 into the furnace shaft. The iron falling into the hearth 5 of the furnace passes through opening 6 and into receiver 7 at the same level. The slag formed during melting is tapped from the furnace through the slag notch 8, while the liquid iron flows into the receiver.

Equal heat between the furnace shaft and the receiver shaft 7 is maintained through an opening at the highest point of the receiver 10. Should the temperature of the iron in the receiver require auxiliary heating, the furnace is constructed without the connecting opening 10. The receiver has a suction

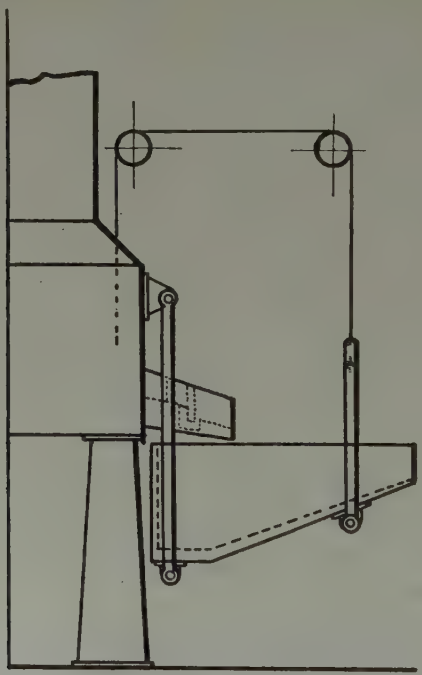


FIG. 63—TILTING TYPE RECEIVER FOR USE WITH THE CUPOLA

pipe 11, which can be closed by a valve 12, and a burner 13 for heating the iron bath by oil, coal dust, gas, coal. This is indicated in the illustration Fig. 64.

Ardelt recently has patented an interesting modification of this type cupola and receiver, in which air introduced into the top portion of the receiver penetrates to the coke by way of the holes in the separating brick roof shown in Fig. 67.

This receiver is embodied in the cupola shaft and is formed by building a special brick bridge across the cupola at a point below the tuyere level. This bridge forms the roof of the cavity

or receiver, into which the metal flows through the circular hole. The arrangement is shown in Fig. 67. Several cupolas equipped with this type receivers are in successful operation today, in several foundries both in this country and on the continent.

A further modification invented by E. Roper & Co., is

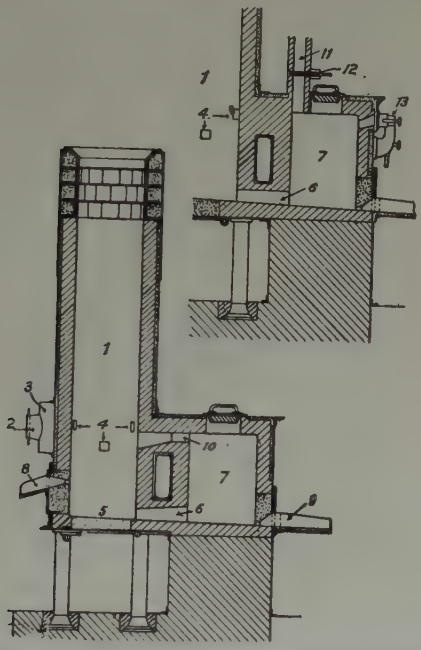


FIG. 64—A RECEIVER WHICH WAS DESIGNED BY ARDELT IN GERMANY

illustrated in Fig. 68. In this arrangement the receiver is constructed separately from the shaft of the cupola, and is mounted on a wheeled carriage on which it may be withdrawn from the cupola for cleaning and fettling purposes. The division bridge across the cupola is constructed of firebrick in a hinged steel framework, attached to the cupola shaft, thereby insuring all the advantages of a drop bottom. Claims for this arrangement are that it eliminates the bed coke, facilitates fettling operations by dispensing with a sand bottom and a fettling door. The loose receiver with the metal supply can be taken direct to the molds,

either on its own bogie, or suspended from the crane. The movable receiver is typical of one used in several other designs, for example, the Klein cupola described in *Stahl und Eisen* 1917. S. 5.

A fore-hearth incorporating a slag removing device and pro-

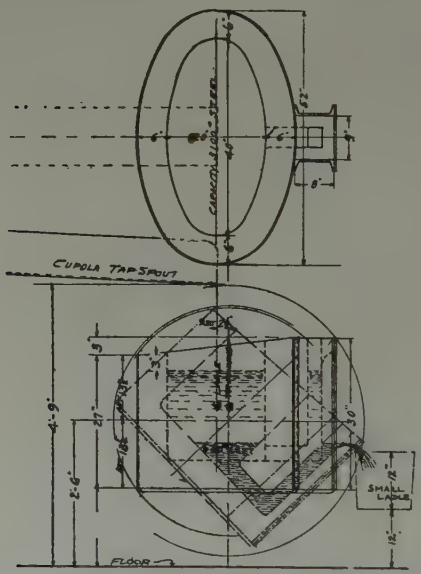


FIG. 65—ELLIPTICAL TYPE RESERVOIR LADLE OF THE TILTING TYPE

vision for auxiliary oil heating shown in Fig. 70 has been designed by the Whiting Corp. Detail method of construction is illustrated clearly in the drawings and needs no further description.

The Hurst oil fired receiver was designed by the author primarily to meet the special requirements of the centrifugal casting process, to provide metal sufficiently superheated, and to organize metal supplies on lines to meet these special requirements. Construction of the non-tilting type of receiver is illustrated in Figs. 71 and 72.

The oil-fired receiver contains a shallow bath constructed of refractory brick and totally enclosed with a refractory roof. The

bath is capable of holding 2 to 3 tons of liquid metal and is provided with a large opening for fettling and constructing the taphole, an inspection door, four holes for the oil burners and outlet ports. The outlet ports are arranged to carry the hot waste

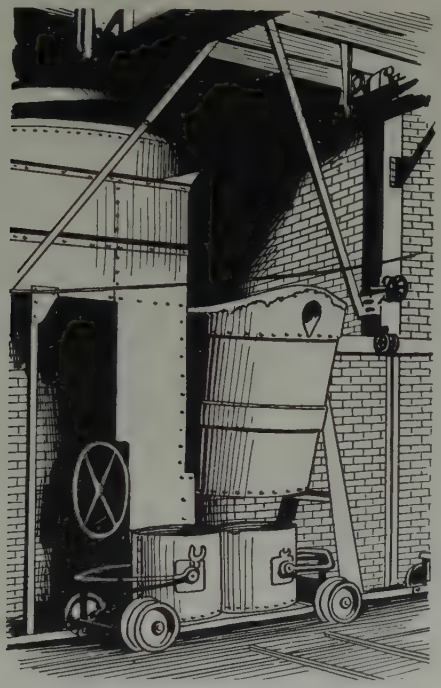


FIG. 66—LARGE RESERVOIR LADLE INSTALLED IN A WHEEL FOUNDRY

gases from the hearth chamber into a small chamber above the roof of the furnace, whence they pass into the air.

Pipes leading air to the oil burners at a pressure of 20 to 25 inches water gage are taken through this roof chamber. During the passage the pressure air becomes heated, thus increasing the economy and efficiency of the burners. Oil is supplied to the burners by gravity feed from a tank supported above the furnace. The oil is elevated to the tank by a small motor-driven rotary pump and is passed through a gauze strainer be-

fore it is led to the burners.

The inspection door is arranged to facilitate removal of samples of the metal for test and to permit addition of pig iron or ferro-alloys to the bath. The breast is closed by a steel sheet held in position by a hinged spout. The tap-hole is built up with black

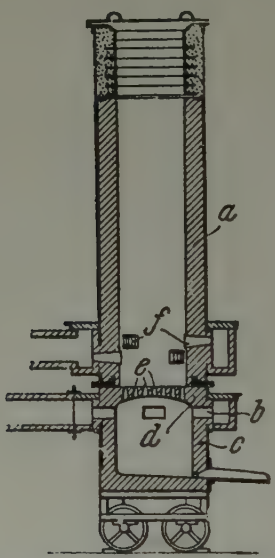


FIG. 67—ARDELT MODIFICATION OF MATCHELL TYPE RECEIVER

sand against coke. After the heat the hinged spout is dropped, the steel breast plate removed and the tap-hole destroyed. Slag and fused material can be raked out and the furnace properly fettled.

In actual operation the full complement of burners are used to raise the temperature sufficiently high to receive the molten metal. Starting from dead cold, this takes from 40 to 60 minutes, but with the receiver in regular use this initial heating period is reduced from 20 to 30 minutes. When the receiver is sufficiently hot, the cupola is started and the molten metal is collected in the receiver. The burners then can be closed down

gradually. Under regular operating conditions one burner is sufficient to maintain the temperature of the receiver.

With this burner system any adjustment can be made according to the demands of the foundry. During experimental

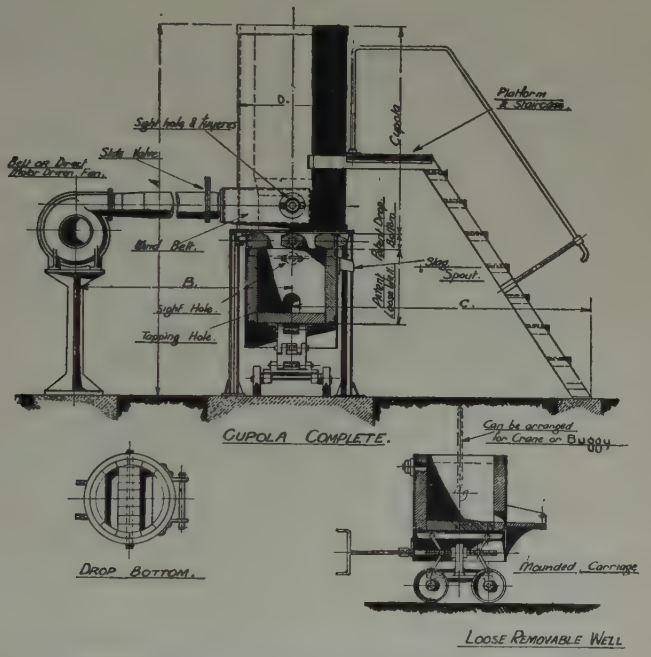


FIG. 68—THE RECEIVER IS CONSTRUCTED SEPARATELY AND IS MOUNTED ON A CARRIAGE

periods as small a quantity as 1000 pounds of molten metal has been held and maintained repeatedly at a perfect casting temperature for periods of 1 to 2 hours. The receiver is mounted on wheels to facilitate repairing. The average oil consumption is from 5 to 8 gallons per hour including oil used in the starting-up period and operating over a total casting period of 6 hours per day. Actual oil consumption per ton obviously depends upon the tonnage of metal handled during this period.

Certain further improvements which have been effected in the design of this receiver are shown in the illustration Fig. 72.

The oil burners in this arrangement send the hot flames and gases directly over the surface of the molten metal collected in the hearth of the receiver and on to the stream of molten metal as it issues from the cupola to the receiver. Additional outlet

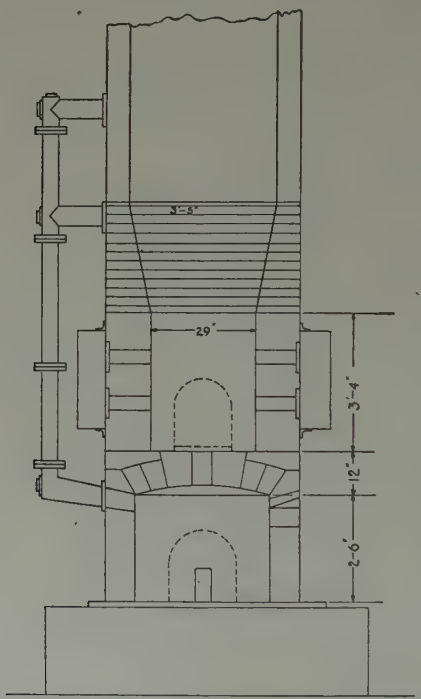


FIG. 69—MATCHELL TYPE CUPOLA AND RECEIVER

ports lead into the chimney over the connecting passage to the cupola. Concentration of the heat in this passage can be controlled by dampers on the main outlet ports.

Under these conditions the molten metal flowing into the receiver in a thin stream is subjected to the intensity of the oil flames. The same oil flames continually playing over the surface of the molten metal in the bath, maintain the superheat imparted to the metal as it enters the receiver. This oil fired receiver also can be constructed as a tilting type, thus eliminating the

necessity for making up the tap hole. Provision also can be made for pouring excess or cold metal back into the receiver. In combination with a slag removing device, the receiver can

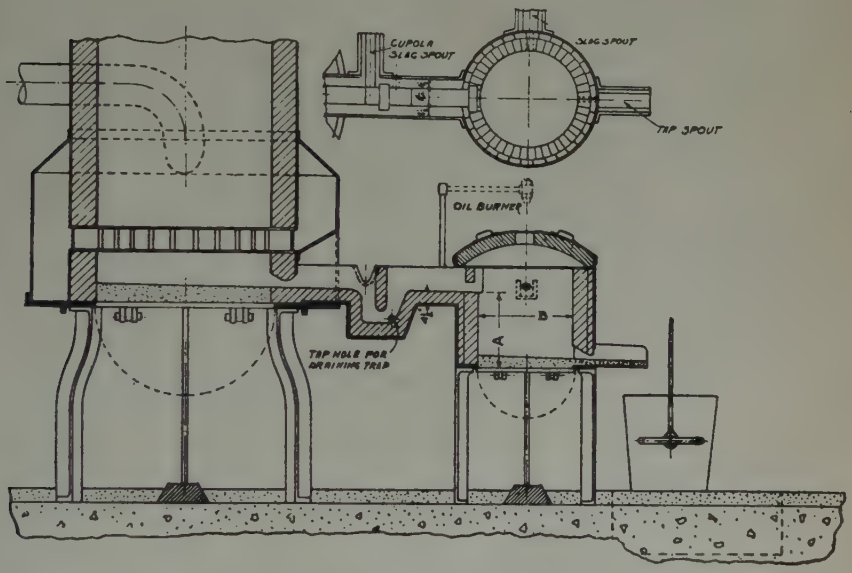


FIG. 70—DIAGRAM OF CUPOLA AND FOREHEARTH MADE BY THE WHITING CORP.

be used for conducting desulphurizing processes and additions of ferroalloys satisfactorily can be made to the metal.

Remelting cast iron in the foundry cupola under normal circumstances generally results in an increase in the sulphur content. Continued remelting of the same material, for example, internal scrap of an individual foundry, conceivably might result in the increase of sulphur content to undesirable proportions. Foundrymen are divided into two clearly defined schools of opinion on the general harmfulness of sulphur in cast iron under ordinary conditions. Both schools agree that sulphur possibly may reach undesirable proportions, but they are not necessarily in agreement on the quantitative expression to be given to undesirable proportions. Necessity for attempting to reduce the sulphur content

while remelting iron in the cupola depends upon the purpose for which the iron is intended, the importance attached to, and the amount of sulphur present. Sulphur normally is maintained within reasonable limits by the addition of limestone in the cupola. For specially reducing the sulphur to somewhat lower limits, ad-

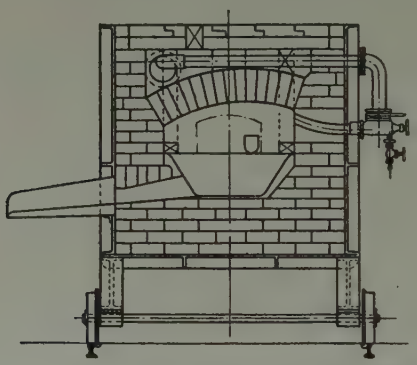


FIG. 71—ANOTHER NONTILTING TYPE RECEIVER

dition of fluorspar or manganese oxides is recommended. In recent years several special processes for effecting desulphurization have come into existence and as these processes generally have involved the use of a receiver, they are worthy of special treatment at this stage.

Use of a basic electric furnace in conjunction with the cupola, now commonly known as the duplex process, has been described fully by various writers including the late G. K. Elliott whose exchange paper "Superheat in the Electric Furnace" appeared in *The Foundry*, Sept. 15, 1921. Undoubtedly this is the most effective method of bringing about desulphurization. The electric furnace superheats and refines the cast iron. The cupola does the initial melting of the iron, thus obviating high current consumption essential to initial melting in the electric furnace. The basic lined electric furnace of the arc type generally is used, and the molten metal is conveyed to it from the cupola in ladles.

Molten metal is retained and superheated in the electric

furnace in conjunction with an active lime slag and appreciable desulphurization is effected. Chemical reactions by which the sulphur is transferred to the slag are of a complex nature, but it is generally agreed that sulphur is taken up by slag in the

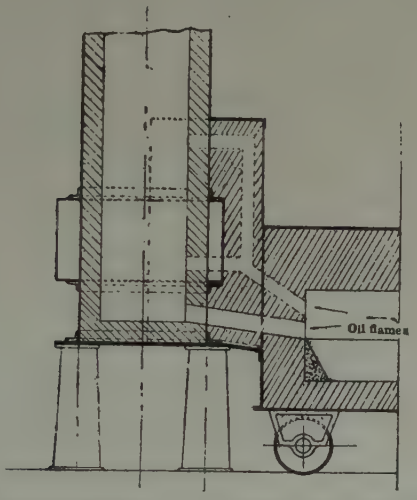


FIG. 72—CONSTRUCTION OF NONTILTING TYPE RECEIVER

form of calcium sulphide (CaS). The following results given by Elliott are illustrative of the process of desulphurization in an iron rich in sulphur:

	Per Cent
As received from cupola	0.156
10 minutes in electric furnace	0.133
20 minutes in electric furnace	0.112
30 minutes in electric furnace	0.079
40 minutes in electric furnace	0.036
50 minutes in electric furnace	0.031
64 minutes in electric furnace	0.014

The Walter-Durkopp-Luyken-Rein process, a combination of various methods devised in Germany, utilizes alkali salts and alkaline earth salts to effect desulphurization. In its earliest form, the desulphurizing slag mixture was added to the molten

metal contained in the ladle. Since these salts produce a covering of liquid slag on the surface of the metal, ladles of the teapot spout type are used, to prevent the inclusion of this slag when pouring metal into the molds.

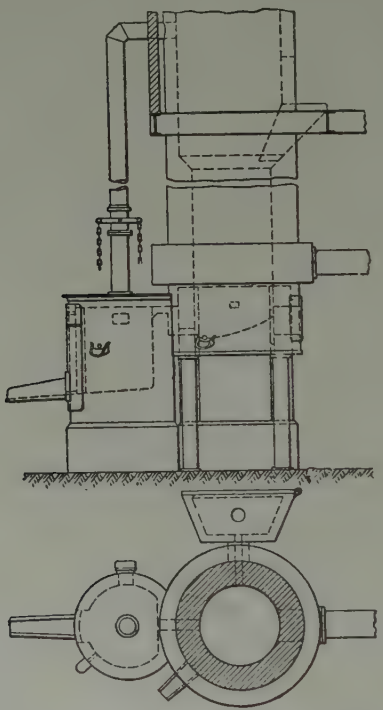


FIG. 73.—CUPOLA WITH DESULPHURIZATION FOREHEARTH, DURKOPP-LUYKEN OVERFLOW AND REIN SLAG RECEIVER

This method was improved in German works by the adoption of various forms of totally enclosed receivers in which the desulphurizing operation was performed and these have culminated in the special design generally referred to as the Rein arrangement. This receiver erected close to the cupola is illustrated in Fig. 73. The connecting passage is arranged, after the manner already indicated in the description of the Ronceray brick, to separate the slag from the metal flowing into the receiver.

On a 40-inch diameter furnace melting about 6 tons per

hour the height of the vertical passage leading to the receiver is about 5 inches and the sectional area 25 square inches. The horizontal passage connecting the receiver and cupola is 2¾ inches wide, 1¼ inches deep and 10 inches in length. The syphon passages presumably hold from 200 to 400 pounds of molten metal.

The Rein construction differs somewhat from the foregoing in that metal and slag flowing from the cupola are deflected to a similar separator arranged in the wall of the receiver. Slag is deflected to a slag box situated outside and adjoining the receiver. Metal flows into the receiver free from slag, an essential factor where desulphurization is to be effected by alkali mixture additions.

Brickwork of the fore-hearth and the overflow demands special attention. Ordinary hard-burnt side-arched brick has proved most resistant. Special bricks are not necessary. An alumina content of 40 to 42 per cent is desirable. However, it is essential that the bricks shall be burnt thoroughly. The bricks should be fitted as closely as possible to avoid large joints. The joints themselves should be packed carefully with the same brick substance. The sulphur slag must be prevented from finding large points of attack in the fore-hearth. Molded bricks made to a special design, according to the circumstances are more suitable for the overflow.

Lower half of the fore-hearth in the furnaces of the Durkopp foundry, is well grouted with a thin loam mortar after every run. Ground fragments of graphite are mixed with the mortar and this materially increases the durability of the fore-hearth lining. For some four or five weeks no additional work worth mentioning is necessary. However, any cracks which develop must be repaired before they get larger.

Cupola slag separated from the metal flowing into the desulphurizing receiver is collected in a separate slag receiver indicated in Fig. 73. The slag receiver on the cupola must not be opened immediately after the run is finished. The solid block of slag is not removed until the following morning. Large furnaces

with a daily melting capacity of 50 tons or more form an exception. Periodic tapping of the furnace slag is desirable, and the doors may be opened sooner—that is, after a few hours. It is advisable to have a special slag receiver for each furnace. The inside of the receiver—the iron plates—are covered with a thin

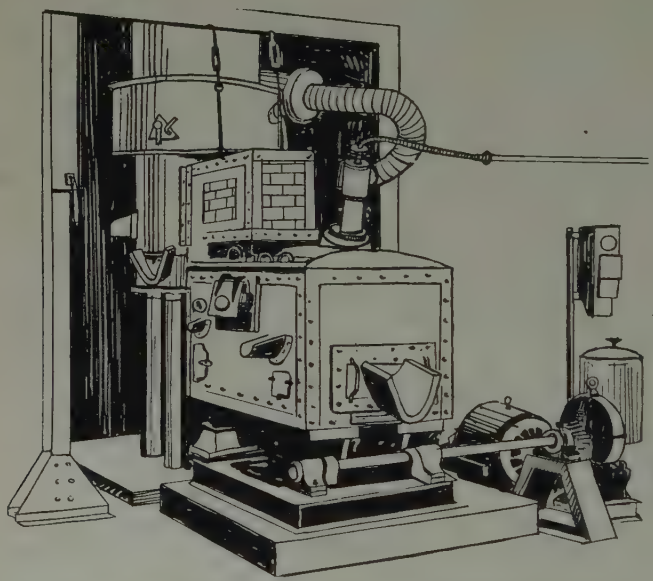


FIG. 74—THE RECEIVER IS HINGED AT THE BACK AND IS JOLTED BY A CAM ARRANGEMENT UNDER THE FRONT

coat of loam each time after they are used. The fore-hearth should be preheated thoroughly before each melting, particularly if it has been repaired.

Desulphurizing reagents consisting principally of soda ash are supplied in small blocks weighing about one pound. Generally speaking, an addition of about 0.5 per cent is sufficient and is claimed to decrease the sulphur content by 40 to 50 per cent. The addition is made as soon as the bottom of the receiver is covered with molten iron. Preferably the material is added in the crushed condition. Care must be taken to keep the fore-hearth as well filled as possible with iron to secure good

desulphurization and maintain the iron at a uniformly high temperature. The level of metal in the receiver should not fall so low that slag collects in the taphole.

Application of the desulphurizing agent takes place in proportion as the iron is drawn from the fore-hearth. For every 1000 kilograms (2200 pounds) of iron drawn, about 5 kilograms

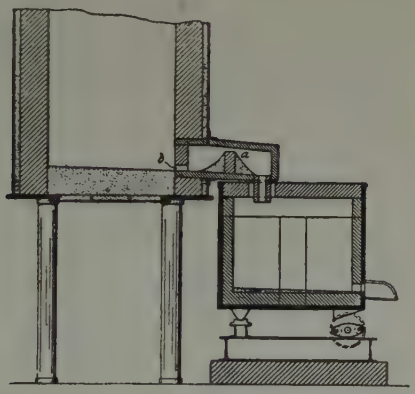


FIG. 75—DECHESNE TYPE JIGGER AND SHAKING RECEIVER IN SECTION

(11 pounds) of desulphurizing briquets should be thrown into the fore-hearth. Addition of the agent then is continued according to the amount of iron required. The desulphurization slag should be thinly liquid and be in constant motion. The degasification generally is clearly visible. Viscous or inert slag indicates some defect in the brickwork of the fore-hearth, or sufficient desulphurizing briquets have not been added.

Claim for the efficacy of alkali salts in desulphurization is not new. In discussing the use of common salt recommended by Calvert a generation ago Dr. Percy states: "Iron masters and blast furnace managers have rather a wholesome dread of blast furnace doctors, especially those who administer nostrums to remove sulphur and phosphorus." The situation has not changed greatly since Dr. Percy's time.

Those who have tried simple additions of alkali fluxes and similar nostrums have met with only partial success. The true

facts of the case are that temperature conditions, the general composition of the iron itself are of greater importance than the character of the fluxing material. The only satisfactory methods of removing sulphur are those of the duplex type already described where the correct temperature conditions can be maintained for sufficient time to enable slags of sufficient basicity to act.

A special type of fore-hearth of receiver so arranged that the molten metal contained therein can be shaken or jolted, has been designed by Dechesne, and described in *The Foundry*, Oct. 1, 1926. This receiver is illustrated in Fig. 75, and a reproduction of a modern installation is shown in Fig. 74. A simple slag separating devices of the usual type is used at *a* and *b* Fig. 75. Jolting of the receiver is actuated by a rotating cam. The receiver is connected freely to the outlet of the slag separating device. The modern jolting installation illustrated in Fig. 74, shows the receiver with an oil burner operating off the cupola air supply. It is claimed that a thorough mixing of all components of the iron is obtained in the jolting receiver, and as a result of the removal of dissolved gases, a close grained, sound material is obtained having a considerably increased tensile strength.

The principal purpose of a receiver is to act as a reservoir, to maintain a constant supply of metal under widely varying demands of the foundry, and thus avoid the violent fluctuations in the working of the cupola, which would be necessary otherwise. Advisability of installing a receiver arrangement depends on particular requirements of the foundry. In a like manner, the same considerations will govern the choice. Successful working of any particular type invariably demands much closer attention to detail, and much more reasonable consideration than is given to many cupola plants today.

CHAPTER VI

Combustion

Economy of cupola operation—Combustion of carbon—Reactivity of coke—The cupola melting zone—Thermal efficiency and the thermal balance sheet—Coke efficiency—Volume, pressure and velocity of air supply—Blast pressure—Velocity of air blast—Rate of melting.

THE cupola has proved the cheapest unit for melting cast iron. This is all the more surprising in view of the admittedly high heat losses due to partially incomplete and indirect combustion of the fuel. Owing to its inherent economy the cupola has retained its position as the foundry melting unit since the early days of the industry. In spite of the economy of this type of furnace, some of the heat losses are so patent and obvious, that even from the early days of its introduction, foundrymen, engineers and metallurgists alike, continually have been striving to eliminate the sources of heat loss and effect further economies and improvements. Many special designs of cupolas have been evolved with this end in view. Extensive investigations have been conducted from time to time into the chemistry of the reactions involved.

Iron is melted in the cupola by heat arising from the combustion of coke. Iron in intimate contact absorbs the heat generated by combustion of coke under the influence of an air blast, injected into the incandescent coke at tuyere level. The most important reaction in the chemistry of the cupola is this combustion reaction, or the oxidation of the carbon. Singularly, this reaction, probably the most important in the structure of civilization, is one of the least understood. Tendency of modern research so far, has been toward increasing the complexity rather than simplifying our understanding of it.

When air is supplied to incandescent fuel, combustion or oxidation takes place, under conditions of complete and entire oxidation, the carbon is oxidized to carbon dioxide (CO_2). When air is passed through a heated column of coke, combustion or oxidation does not take place completely in this manner. A

certain amount of the lower oxide of carbon, carbon monoxide (CO) is formed. Theoretically this is due to a secondary reaction between the carbon dioxide already formed, and the heated carbon, with which this reacts, forming carbon monoxide in the manner expressed symbolically by the equation $CO_2 + C = 2CO$. Consideration of these reactions in this manner involves the assumption that the formation of carbon dioxide takes place

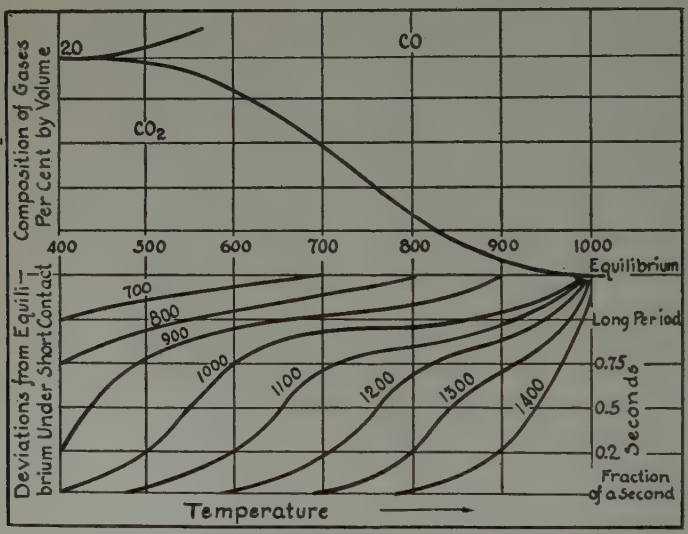


FIG. 76—BOUDOUARD'S DIAGRAM WITH EXTENSIONS

first. On this point, considerable doubt exists. Many chemists present reasonable grounds for considering that carbon monoxide is formed first, while other chemists hold the view that the two oxides are formed simultaneously. This latter view probably is the more correct, and should be of interest to the foundryman since it bears on cupola practice.

Relative extent of these two reactions taking place under any given set of circumstances is extremely important, as shown by the following figures giving the heat value of the two reactions:

(a) Direct combustion of C to CO_2 evolves 4450 B.t.u.'s per pound of carbon.

(b) Direct combustion of C to CO evolves 4350 B.t.u.'s per pound of carbon.

(c) Direct combustion of CO to CO_2 evolves 4350 B.t.u.'s per pound of CO.

The subsidiary reaction by which CO_2 in the presence of carbon is transformed to CO is a reversible reaction, and has been studied by many chemists including Boudouard, Schenck, Le Chatelier, and others. Percentages of CO_2 and CO formed in contact with solid incandescent carbon under conditions of equilibrium are illustrated in Fig. 76. At a temperature of 1000 degrees Cent., carbon monoxide (CO) is the only oxide of carbon remaining in equilibrium in the presence of solid carbon at this temperature. Lines on this diagram hold only under normal conditions of pressure and it has been shown (Schenck, *Chimie Physique*, Paris, 1911) that these equilibrium values vary considerably with the form of the carbon. Graphite does not give the same results as wood charcoal, nor does wood charcoal give the same results as sugar charcoal. The same remarks apply with different varieties of coke. Koppers has shown that the amount of CO formed, varies considerably with the physical character of the coke, other conditions being maintained constant. Soft, easily burnt varieties of coke produce considerably more carbon monoxide than hard, less easily burnt varieties.

Observations of Koppers introduces a property of coke, under the heading of reactivity, which has been the subject of much discussion of late, in both cupola and blast furnace practice. The property of reactivity in coke is the extent to which it is capable of reducing CO_2 to CO. From what has been said previously it will be apparent that this to some extent is determined by its physical or physico-mechanical characteristics. Dr. Koppers has demonstrated this property in a beautiful manner, by burning different varieties of coke of equal size in small vertical furnaces, under equal blast pressures and quantities. Soft, easily burnt varieties produce chiefly carbon monoxide, indicated by the long blue flame issuing from the furnace. According to

the increase in hardness and density of the coke, the carbon monoxide flame becomes shorter, indicating the greater production of carbon dioxide. This is diagrammatically shown in Fig. 78. Physical characteristics of the coke exert a considerable influence on the reactivity, but it is influenced also by other conditions, one of which is temperature. As the temperature rises, the reactivity of coke increases.

Significance of this property of reactivity of coke in cupola practice is summed up briefly in Dr. Koppers' own words. "In the blast furnace, the coke must convert the carbon dioxide as rapidly as possible into carbon monoxide. In the cupola, to obtain the greater heat development the coke should react as little as possible with the carbon dioxide. Under these conditions the processes are carried out with the least consumption of fuel, and give the greatest yields. Easily consumable blast furnace cokes are produced at the lowest temperature possible. Foundry coke is made dense and slow burning by production at a higher temperature."

These considerations show that reactivity of coke is of great importance in cupola practice. However, in the present knowledge of this property the foundryman would be extremely unwise to arrive at the dogmatic conclusion that the least reactive coke is ideal for cupola practice.

Those who desire to pursue this subject further should study the very carefully thought-out considerations of Prof. Thompson, which appeared in the *Journal* of the Institute of British Foundrymen, 1925-1926. They lead to the conclusion that "if reactivity means anything at all in cupola practice, and that is a matter which can be determined by experiment only, a reactive coke should be chosen. Indeed, if such a fuel does bring about economy in the blast furnaces, there is no reason which the author can see why it would not be equally beneficial in the cupola."

Reactivity also is influenced profoundly by catalytic agents. Iron acts as a powerful catalyst in this instance. Other conditions to be considered in determining the completeness of such reversible reactions, include physical character of the reacting

bodies, velocity of the reactions and the time available for their completion. This has been indicated in a recent paper by Koppers, *Stahl und Eisen,* August, 1921, in which he calls attention to the work of the American investigators, Clement, Adams, and Haskins, *Bulletin No.* 7, bureau of mines, who have

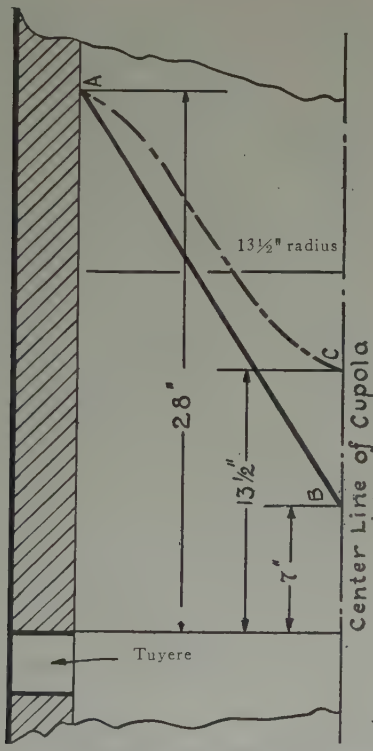


FIG. 77—LAST TRACES OF OXYGEN AND MAXIMUM PERCENTAGE OF CO_2 ARE SHOWN BY LINES AB AND AC

investigated some deviations from Boudouard's equations for various fuels and various times of contact. Some of these results have been appended to the diagram in Fig. 76.

Combustion of coke in the cupola probably is far removed from equilibrium conditions. Rapid passage of gas through the column of coke in the cupola stack, constantly changes the atmosphere at any one point, and prevents attainment of anything

like equilibrium conditions. Value of investigations under equilibrium conditions lies in the provision of a fundamental standard with which to compare results obtained under actual practical working conditions.

Existing knowledge of the equilibrium conditions lead us to one perfectly definite conclusion. Combustion of coke under ordinary cupola operating conditions must be accompanied inevitably by the formation of some carbon monoxide. This undoubtedly constitutes the fundamental problem in the efficient operation of the cupola. The aim and object of all work toward economy of the cupola must be to maintain the conditions that will result in the formation of a minimum amount of carbon monoxide.

Observation of practical cupola operation clearly shows that a more or less well defined zone establishes itself in the completely charged stack within the confines of which melting takes place. This melting zone is bounded on its lower side by an area slightly above the tuyere level. Any person looking through the tuyeres can see iron at this level in the form of molten drops. Foundrymen who have had the unfortunate experience of seeing solid metal reach a level below the tuyeres know that no melting takes place below this level, at least in any reasonable time.

When air is injected into a column of incandescent coke at a predetermined level, the coke commences to burn. Extent of combustion will depend upon amounts of participating constituents, air and the coke, other conditions remaining constant. Under a given set of conditions, a zone of combustion will be established rapidly.

If air, uniform in quantity and velocity, is supplied to all points across the section of a cylindrical coke column at the same time, and if the coke is uniform in size, shape and area exposed, combustion should take place uniformly. The combustion zone would show a parallel section across the cylinder at a height depending upon the amount of air that is supplied.

These uniform conditions do not obtain in practice. Air injected at the outside surface of the cylindrical column does not penetrate evenly to the center of the mass, and combustion

does not take place evenly across the section. Maximum combustion around the outside surface of the cylindrical column is a thoroughly well known and easily observed fact and therefore the upper surface of the combustion zone roughly must take the form of an inverted cone.

Detailed investigation carried out under the auspices of

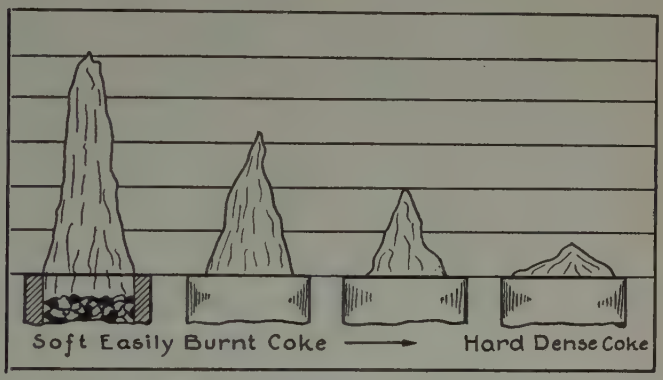


FIG. 78—DIAGRAMMATIC PRESENTATION OF CO FLAME FROM VARIOUS QUALITIES OF COKE

the United States bureau of mines, *Bulletin No.* 54, in which gas samples were obtained and analyzed from the center to the outside edge of the cupola at different levels, serve to locate the upper limit of the melting zone with great accuracy. The cupola was lined to 27 inches diameter at the tuyere level, and air was used at 5.3 ounces per square inch pressure and a velocity of 1000 cubic feet per minute. Presence of free oxygen in the gases from any given point was accepted as evidence of the completeness of combustion. Analyses showing the maximum CO_2 content were taken as indicating the highest temperature conditions. The smooth curves *AB* and *AC* drawn through the points of the last traces of oxygen content and the maximum percentage of CO_2 are shown in relation to the cupola in Fig. 77. These indicate respectively the upper limit of complete combustion and the upper limit of maximum temperature and these two curves may be taken as locating the limits of the upper

surface of the melting zone. They confirm the general deduction that this upper surface is more or less conical in shape.

Analyses of gas samples from which this shape of the upper surface of the melting zone has been deduced are given in Table VI. The samples were taken at five different planes, commencing at plane *A*, 1 inch above the top of the inner opening of the tuyeres. Planes *B*, *C*, and *D* are at higher levels 6 inches apart and the last plane *E*, was at a distance of 7½ inches from

Table VI

GAS SAMPLE ANALYSES

Plane	Location	—Average of 5 Tests— CO_2	O_2	CO	Plane	Location	—Average of 5 Tests— CO_2	O_2	CO
A	1	12.0	0.2	14.2	D	1	9.8	0.0	18.1
	2	10.3	2.1	14.0		2	11.5	0.0	15.4
	3	4.5	15.8	0.2		3	16.9	0.4	4.8
B	1	13.1	0.1	12.4	E	1	8.6	0.0	19.9
	2	12.5	0.3	12.9		2	10.1	0.0	17.1
	3	11.5	8.9	0.5		3	15.2	0.1	6.8
C	1	11.9	0.1	14.4					
	2	12.8	0.1	13.2					
	3	15.0	4.9	1.0					

plane *D*. Three samples were taken from each plane, commencing with sample 1 at the center, and samples 2 and 3 at equally spaced intervals of 4½ inches radially toward the cupola wall.

Average of five repeated series of tests are included in the table shown. These actual analyses trace the course of combustion reaction in the melting zone of the cupola referred to in commencement of these notes. With the introduction of air approximately at the tuyere level, almost complete combustion has taken place at the center of the mass of incandescent coke, as indicated by the almost complete absence of free oxygen (Sample 1, zone *A*). At a point closer to the lining, combustion is far from complete and the combustion becomes complete at this point only at zone *E*. (Sample 1, zone *E*.) In the presence of excess air a little carbon monoxide is formed, and this increases steadily as the excess air decreases (Samples *A*3, *B*3, *C*3, *D*3, *E*3). Despite traces of excess air in the central portions of the zones where combustion is almost complete, a large amount of carbon monoxide accompanies the carbon dioxide already

formed. These facts are of interest in determining which of the two is formed first, CO_2 or CO. This example appears to indicate that both these oxides of carbon are formed simultaneously.

Analyses of samples taken from the center of the charge afford a splendid example of the secondary reaction in which the CO_2 already formed is converted to CO in accordance with the equation $CO_2 + C = 2CO$. This reaction is endothermic, absorbs a large quantity of heat and sets a limit to the hottest zone of combustion. Actual tests show that CO is produced along with CO_2 immediately at the commencement of the melting zone and that the amount of CO tends to increase as a result of the secondary reaction between the CO_2 and the incandescent carbon.

A note of warning is necessary regarding the accuracy of either gas analyses or temperature measurements taken inside a working cupola. Where the difficulties of ensuring representative samples and conditions at any one point are almost insurmountable. This will be appreciated readily after a moment's consideration of the rapidity of the change in conditions which must take place at any given point during the cupola operation. These difficulties are evidenced in the wide discrepancies frequently found in many published results by different investigators and which are finally responsible for variations in expression of the theory of combustion in the cupola referred to originally. However, the facts already indicated relating to the early, probably immediate formation of carbon monoxide along with carbon dioxide and the subsequent reduction of the carbon dioxide to carbon monoxide are amply supported by evidence, and are qualitatively, if not quantitatively in accordance with expectations from equilibrium considerations.

Thermal efficiency of the cupola is determined from the complete thermal balance sheet of the melting operation in which heat input from all sources is balanced against heat output. Heat output in molten metal itself expressed as a percentage of the heat input from all sources is the value used to express the thermal efficiency of the cupola.

A number of attempts have been made to draw up complete thermal balance sheets of the cupola melting operation. Before

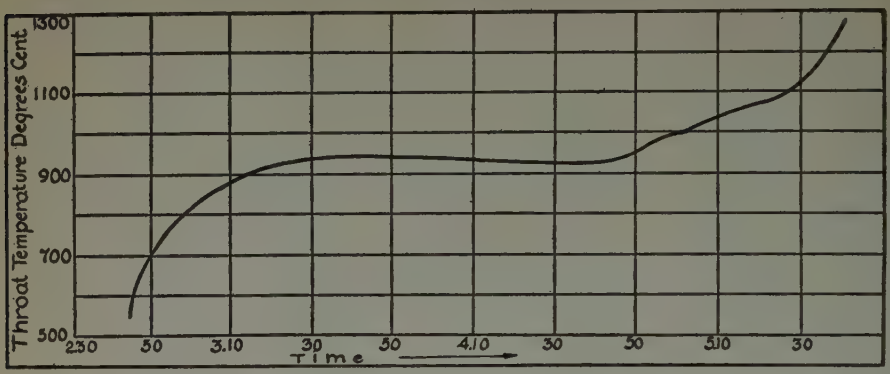


FIG. 79—TEMPERATURES OF EXIT ACCORDING TO PIWOWARSKY AND BROGLIO

considering these in detail it is necessary to draw attention to the great difficulties encountered in obtaining comparative and complete data. Difficulty arises from the innumerable variations in practice and operation of cupolas necessitated by varied requirements of foundries, by intermittent character of working of cupolas and uncertainty of accuracy of various physical constants used in calculating the heat values from the observed data.

Probably the outstanding difficulty is the intermittent character of the working. Majority of cupolas run for a few hours daily, a practice which entails: (a) A starting up period when

Table VII

THERMAL BALANCE SHEET OF PIWOWARSKY AND BROGLIO

Heat Input	Kg. calories
(1) Latent heat of coke	18,616,320
(2) Oxidation of iron	983,512
(3) Heat of charge	210,947
(4) Other exothermic reations	5,088
Total	19,815,867

Disposition of Heat	Kg. calories	Percentage of total
(1) Heat content of molten iron	52,629,000	28.3
(2) Conduction, radiation and losses due to escape of gases	464,776	2.4
(3) Heat to form molten slag	734,751	3.5
(4) Heat lost when emptying furnace	131,120	0.6
(5) Sensible heat lost in gases	4,723,310	24.2
(6) Latent heat lost in gases	7,736,457	39.0
(7) Endothermic reaction	396,453	2.0
	19,815,867	100.0

lining, shell, etc., are cold and require to be heated. (b) A normal period when the cupola is running under steady conditions. (c) A final or blowing down period when the cupola is emptying itself and volume of charge in the stack is reduced steadily and not maintained by new additions. Obviously proportion of

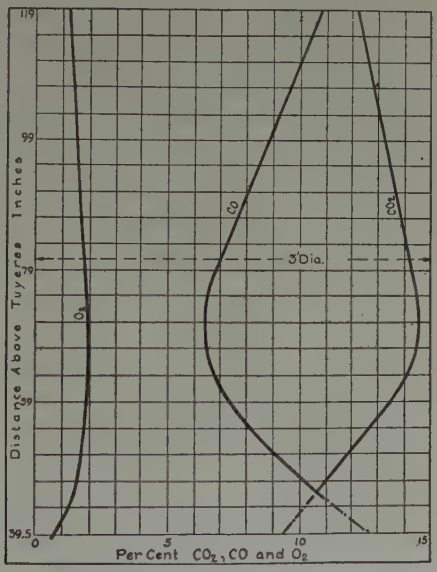


FIG. 80—GAS COMPOSITIONS AT DIFFERENT LEVELS

total operating time occupied by each of these three stages will vary considerably in different cupolas and vitally will affect the thermal efficiency.

One of the earliest published balance sheets appeared in *The Foundry* some years ago. Some doubt attaches to the accuracy of the various temperature measurements in this instance, but it is of interest to record that only 27.5 per cent of the total heat input was found to be used in the melting and superheating of the iron. Approximately 50 per cent of the heat input was lost in the form of sensible and latent heat in the outgoing gases.

Data for an extremely interesting thermal balance sheet

prepared by Piwowarsky and Broglio in Table VII were obtained from the operation of a cupola of the following dimensions:

Overall height to charging door	13.1 feet
Inside diameter	35.4 inches
Outside diameter	62.4 inches
Thickness of lining (walls)	15 inches
Thickness of lining (bottom)	18 inches
Ratio tuyere area to furnace area 0.20 at beginning, 0.30 at the end	
Blast main diameter	14 inches

The coke used in this experiment contained 10.70 per cent ash, and 6.70 per cent moisture. Complete analysis follows:

	Per cent
Carbon	80.19
Iron	1.21
Sulphur	1.30
Ash	10.40
Moisture	6.70

The coke consumption was 16.6 per cent or a ratio of 1:6.25 made up as follows:

	Kilograms	Pounds
Bed coke	750	1650
Melting coke	2275	5014
Total	3025	6667
Coke recovered from dump	145	319
Total consumption	2880	6347
Percentage	16.6	

Coke used in these tests was poor and below the average.

The throat temperatures varied from approximately 500 degrees Cent. to over 1500 degrees Cent. as indicated in the diagram Fig. 79, and the gas composition at different levels is indicated diagrammatically in Fig. 80. Composition of escaping gases is not given. Calculated temperatures on the outside of the furnace shell follow:

	Degrees Cent.
Bottom zone	143
Melting zone	132
Middle zone	130
Throat zone	75

Diameters of the melting zone before and after the experiment were respectively 37.6 and 40 inches, and the height 35 inches.

Some remarkably high thermal efficiency figures obtained in a series of further tests by Piwowarsky and Meyer are shown in Tables VIII and IX. These tests were carried out in the foundry of Sulzer Bros., Winterthur, Switzerland on a cupola equipped with a fore-hearth. The diameter of the cupola at the melting zone was 29 inches, expanding to 39 inches above the melting zone. The cupola was equipped with two rows of tuyeres 15.7 inches apart. Each of the eight tuyeres in the upper row was 3 inches square, each one of the four in the bottom row was 4.3 x 5.5 inches or 24 square inches area. The total tuyere area of 168 square inches gives a ratio of tuyere area to melting zone area of 1 to 3.94.

Composition of the metal used in the experiments varied between the limits of silicon content of 1 to 2.75 per cent and phosphorus content of 0.10 to 0.81 per cent. Analysis of the coke follows:

Fixed Carbon	85.62 per cent
Ash	10.49 per cent
Moisture	2.88 per cent
Sulphur	1.01 per cent

In the *Foundry Trade Journal*, April 8, 1926, Hejemana records thermal efficiencies in three tests of 20.5 per cent, 35.8 per cent and 42.3 per cent with coke consumptions of 20.5 per cent, 13.9 per cent and 10.5 per cent respectively. The heating value of the coke in these instances was 6800 calories per kilogram.

Thermal efficiencies and losses abstracted from various published balance sheets are summarized in Table IX. The wide

Table VIII

PIWOWARSKY AND MEYERS RESULTS

Test series	1	2	3	4	5	6	3	7	8	9	10
Iron charged kilos.	19,210	22,630	20,438	21,130	21,320	20,970	20,438	19,220	20,160	18,720	20,010
Yield of iron Kg.	18,999	22,410	20,214	20,898	21,086	20,739	20,214	19,008	19,938	18,519	19,790
Bed coke Kg.	450	450	450	450	450	450	450	450	450	450	450
Charge coke Kg.	1,470	1,720	1,450	1,530	1,590	1,320	1,490	1,690	2,010	2,085	2,480
Coke recovered Kg.	160	115	110	80	70	117	110	268	182	273	171
Charge coke per cent per ton of iron...	7.65	7.60	7.42	7.24	7.46	6.29	7.42	8.79	9.36	11.12	12.38
Total coke per cent of iron.	9.25	9.08	8.96	8.99	9.24	7.88	8.96	9.74	10.51	12.08	13.79
Blast pressure ins. of water.	9.8	12.2	15.7	18.1	22.8	15.7	15.7	15.7	15.7	1.57	15.7
Quantity of blast cubic feet per min....	1,260	1,588	2,118	2,259	2,647	2,118	2,118	2,118	2,118	2,118	2,118
Proportion of CO_2 to CO.	76:24	74:26	86:14	74:26	78:22	88:12	86:14	73:27	66:34	62:38	60:40
Throat losses per cent of total heat input—											
Perceptible.	7.21	6.61	7.39	7.68	0.64	7.05	7.39	7.74	7.71	9.23	12.23
Latent.	16.45	19.7	9.48	22.34	20.7	8.64	9.48	21.06	26.60	33.26	32.44
Thermal efficiency per cent.	42.0	43.8	46.7	44.4	43.2	51.3	46.7	40.7	35.1	32.9	28.8
Time of heat in minutes.	376	372	265	280	275	245	264	270	310	322	370
Production tons per hour.	3.20	3.61	4.58	4.48	4.61	5.08	4.58	4.23	3.86	3.45	3.21
Tapping Temperature in degrees C.											
Of iron.	1,370	1,433	1,436	1,440	1,452	1,411	1,436	1,445	1,438	1,420	1,435
Of slag.	1,414	1,460	1,457	1,468	1,492	1,450	1,460	1,485	1,461	1,443	1,507

Table IX

SUMMARY OF THERMAL EFFICIENCY TESTS

Thermal balance No.	(1) Heat lost by radiation from furnace lining	(2) Heat to decompose limestone	(3) Heat to Evap. moisture in coke	(4) Heat in unburnt coke	(5) Heat to raise Temp. of furnace lining	(6) Heat unaccounted for	(7) Heat to form molten slag	(8) Sensible heat lost in gases	(9) Latent heat lost in gases	(10) Heat to melt and superheat iron	(11) Thermal efficiency
1	0.18	1.84	....	1.63	13.34	1.30	4.66	24.15	25.40	27.5	27.5
2	2.4(1)	2.0(2)	....	0.60	....	....	3.7	24.6	39.0	28.5	28.5
3(3)	....	....	....	....	....	....	....	7.05	8.64	51.3	51.3
4(4)	....	....	....	....	....	....	....	12.23	32.44	28.8	28.8
5	....	2.7	1.6	....	....	18.0(5)	4.3	....	26.0	47.0	47.0
6	....	....	....	....	....	16.2(6)	2.9	17.9	42.5	20.5	20.5

NOTE: (1) Probably includes other small items.
(2) Total heat from all endothermic reactions.
(3) and (4) The best and worst of Piwowarsky & Meyers results.
(5) and (6) Probably inclusive of all heat under headings not estimated.

variation in thermal efficiencies is an index of the differences already anticipated. However, the summary is useful in indicating from various investigations the magnitude of heat losses in various directions. Considering the wide variety of practical conditions represented by these tests, the agreement of the results in certain particulars is quite remarkable.

The two principal items constituting heat losses are the sensible and latent heat carried away by the escaping gases. Sensible heat is that contained in the escaping gases by which they are maintained at the observed temperature of exit. Latent heat is that heat which would be utilized in the cupola if the carbon monoxide which the gases contain were completely burned to carbon dioxide.

Attempts have been made to ascertain the theoretical limit of thermal efficiency that can be obtained using coke and air exactly as under commercial conditions. These theoretical considerations have been carefully examined by Thompson and Becker as a result of which they have been able to construct an equation which can be utilized in determining the theoretical limit of the thermal efficiency. With tapping temperature of the molten metal of 1425 degrees Cent., temperature of the exit gases 425 degrees Cent. and a CO/CO_2 ratio of 1 the theoretical limit of thermal efficiency is determined as 52.6 per cent of the total heat available from the coke or 49.1 per cent of the total heat input from all sources.

Thompson and Becker, *Journal*, Institute British Foundrymen, 1925-26, p. 162, clearly demonstrate that consideration of thermal efficiency of the cupola is incomplete without reference to three things: Tapping temperature of the molten metal, temperature of the escaping gases and CO/CO_2 ratio in the escaping gases. This often is overlooked in consideration of cupola efficiency.

The foundryman principally is concerned with fuel economy. For example, a conceivably high thermal efficiency coupled with a high tapping temperature is of no interest to the foundryman if the tapping temperature is higher than his requirements and is not accompanied by the most economical consumption of fuel. He desires the lowest coke consumption coupled with a

tapping temperature sufficiently high for his requirements, in other words the highest coke efficiency.

Among foundrymen the most common method of expressing coke consumption is in the form of a simple ratio between amount of coke used and amount of iron melted. In spite of the more modern tendency to express this ratio as a percentage it is the simplest and the most generally understood. In whatever manner the coke consumption is expressed, little investigation is necessary to show that this apparently simple and direct practice is not the most definable of the many indefinite practices in the foundry. Many complications arise which provide some of the most controversial points in foundry discussions.

Inclusion of the bed coke in the coke ratio, formerly a contentious point, appears to be settled by general consent, and the commonly accepted coke ratio is understood to include the whole of the bed coke. Strictly speaking some of this coke is recovered from the dump, and the amount thus recovered should be deducted from the total to obtain the correct ratio. It is done in thermal efficiency investigations, but it is much too difficult and laborious a task for daily melting practice. The more modern method of dividing the total coke consumption into two items of bed coke and melting or fusion coke has been adopted widely. It may be expressed either as a ratio or a percentage of the iron melted whichever is more readily conceived or understood.

Considerations of coke ratio and economy often are confused by statements of the theoretical limiting coke ratio appearing in many textbooks. A typical example taken from a carefully written treatise on foundry practice follows: "The heat generated by one pound of carbon should be capable of melting about 40 pounds of iron if the combustion were complete and the absorption perfect."

This coke ratio of 1 to 40 or 2½ per cent, in spite of its careful definition with respect of the completeness of combustion and heat absorption, is based on the assumption of pure carbon as fuel and the whole of the heat evolved in the combustion being completely absorbed by the iron to be melted. To translate this into foundry practice it means that a coke ratio of 1 to 40

would be obtained using pure carbon as fuel, with the escaping gases containing no free carbon monoxide and at the same temperature as the atmosphere. Clearly these conditions do not represent conditions attainable in practice.

Presence of 12½ per cent ash in the coke, not an infrequent percentage, reduces this coke ratio to 1 to 30 with a tapping temperature of the molten metal of 1450 degrees Cent. It is impossible to burn coke in shaft furnaces without formation of some carbon monoxide. Escaping gases cannot issue from the cupola throat without carrying away some sensible heat. Additional heat of necessity must be absorbed in formation and melting of slag, in heating and radiation from the furnace lining. All these sources of heat absorption are inherent features and must be taken into consideration in determining the theoretical limit of coke ratio obtainable in cupola practice. They reduce the coke ratio to a still further lower figure.

In attempting to ascertain the theoretical limiting coke ratio it is conceivable that general agreement might be obtained on the practical limiting ash content of the fuel and a comparative tapping temperature. In the present state of our knowledge it is improbable that we should obtain general agreement on the limiting conditions of escaping gas composition and temperature.

However, the equation deduced by Thompson and Becker referred to previously enables us to ascertain the theoretical limit to which the coke ratio could be pushed under conditions of: (a) Stipulated tapping temperature (b) escaping gas composition (c) escaping gas temperature (d) carbon content of coke and (e) heat loss by way of slag, absorption by endothermic reactions, furnace lining and radiation losses.

With a tapping temperature of 1425 degrees Cent. escaping gas containing equal volumes of CO_2 and CO; escaping gas temperature of 425 degrees Cent. and coke of an ash content of 12.5 per cent the coke ratio is 15.4. Where the same tapping temperature is assumed, but the escaping gas is free from carbon monoxide and at room temperature it would be possible to obtain a ratio of 1 to 30, in other words, to melt one ton of iron

with approximately 70 pounds of coke with an ash content of 12½ per cent. These values of course relate to melting coke only.

Closeness with which the foregoing theoretical limit can be approached in practice with any given coke and the same tapping temperature of the iron is determined by how close the escaping gas temperature and composition can be made to approach those

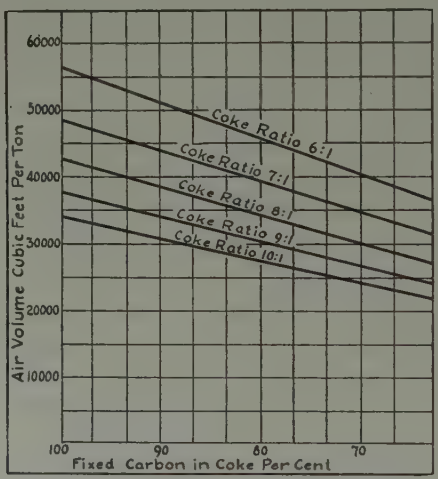


FIG. 81—AIR VOLUMES VARYING WITH FIXED CARBON IN COKE AND COKE RATIOS

specified in the limiting conditions mentioned. This is borne out by examination of heat losses in Table IX, which shows that at least 40 per cent of available heat in coke is absorbed in sensible and latent heat of escaping gases.

Many cupolas have been designed to minimize these particular losses and thus improve economy of the cupola. The whole problem is complicated far beyond the comparatively simple consideration of coke combustion by many other variable factors including; proportionality of height to diameter of the stack, number, shape and disposition of the tuyeres, quantity, velocity and pressure of air supply, shape of the internal lining of the cupola. In view of these complexities the only course left open in further consideration of economy of the cupola, is to consider

the manner in which the operation adjusts itself in practice as determined by further experiments.

Theoretical considerations and actual experiment serve to show the importance of quantity, velocity and pressure of the air supply, the other constituent of the combustion reaction.

Quantity of air required to burn 1 pound of fuel is determined by the relation: Air required in pounds = 0.116 [C + 3 (H — ⅛ O)] where C., H. and O. are the respective amounts of carbon, hydrogen and oxygen in the fuel being burned in the cupola.

Table X

VOLUME OF AIR REQUIRED UNDER VARYING CONDITIONS

Percentage fixed carbon	Air required in lbs.	Air required in cu. ft.	Air required in cubic feet per ton with coke ratios				
			10:1	9:1	8:1	7:1	6:1
100	11.6	152	34,048	37,720	42,560	48,638	56,746
90	10.44	137	30,600	34,150	38,400	43,750	51,000
80	9.39	123	27,552	30,613	34,440	39,360	45,920

For cupola purposes where coke only is used as fuel, the amounts of hydrogen and oxygen can be neglected. Amount of air required to burn one pound of coke will depend upon its fixed carbon content or conversely its ash content. These values for cokes varying from 0 to 20 per cent ash are given in Table X. In accordance with the method in common use, air quantities per ton of iron melted with coke ratios varying from 1 to 10 to 1 to 6 have been included in the table and are plotted diagrammatically in Fig. 81.

Consideration of various carefully conducted trials points to the existence of a critical quantity of air supply which is accompanied by the best efficiency under given conditions of cupola design and working. Examination of the summary of results obtained by Piwowarsky and Meyer discloses existence of a critical air supply of 2118 cubic feet per minute accompanied by maximum thermal efficiency of 46.7 per cent and the maximum melting rate of 4.58 tons per hour under conditions of approximately constant coke ratio. In the further series of

tests Piwowarsky and Broglio demonstrated maximum thermal efficiency and melting capacity curves coincident with a critical blast volume as illustrated in Fig. 83.

Further confirmation still is to be had from recent investigations of P. H. Wilson which clearly show the existence of the most efficient CO_2 and CO ratio coincident with critical

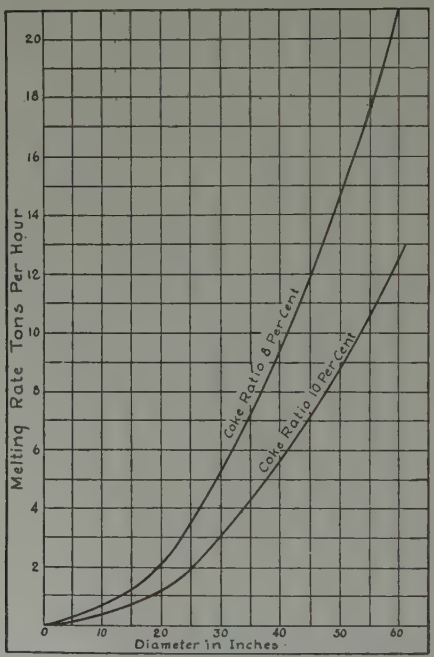


FIG. 82—DIAMETER OF CUPOLAS AND MELTING RATE

blast volume. In all these cases the critical blast volume is slightly in excess of the theoretical quantity calculated according to the quality of coke and the coke ratio. This is clearly shown in Table XI from the calculations summarized therein.

The plan followed by Piwowarsky in determining conditions for any particular cupola occupied two stages. Operating with an approximately constant coke ratio the optimum conditions of blast quantity were determined from the determination of the thermal efficiencies. In the second stage operating with this

optimum blast volume the coke ratios were varied, and the low limit of 6.29 per cent was fixed apparently by the observed commencement of a decline in tapping temperature of the metal. Two of the conclusions are of sufficient interest to repeat verbatim, "(a) In each case the consequences of an excessive coke charge are more detrimental (to the thermal efficiency) than the consequences of too little air or a slight excess of air and (b) the fear that the reduction in the charge coke might cause increased

Table XI

COMPARISON OF ACTUAL CRITICAL AIR AND THEORETICAL AIR QUANTITIES

Thermal efficiency	Coke per cent	Fixed carbon per cent	Tons per hour	Actual air cu. ft./min.	Theoretical air cu. ft./min.
46.7	8.96	85.62	4.58	2118	1999
51.3	7.88	85.62	5.08	2118	1944

losses is only founded where the charge coke is below 7 per cent."

Necessity for consideration of blast pressure arises out of need for consideration of penetration of the blast to the center of the coke charge. Steady development in the use of fan blowers in the early days caused some confusion among foundrymen in interpreting the meaning of blast pressure.

Indicated delivery pressure of fan blowers partially depends upon resistance offered to passage of air and does not necessarily indicate the effectiveness of air penetration into the charge. For this reason knowledge of volume of air delivered to the cupola per unit time becomes of increasing importance.

Importance of blast pressure in cupola practice probably depends upon the internal diameter. Under normal conditions blast pressure must give some indication of the efficiency of penetration to the center of the coke charge. Probably this is of greater importance in large than in smaller diameter cupolas and is responsible for general recommendation of an increase in blast pressure with an increase in diameter. A typical example of recommended blast pressures for increasing diameters of cupolas is given in Table XII. These recommendations are presented as typical and it will be found that the blast pressures recommended cover substantially wide range for any one

given diameter of cupola. Modern tendency is toward lower pressures, provided the correct quantity of air is delivered. Pressure of air discharging under constant conditions increases as the square of the velocity and consequently lower pressure is equivalent to lower air velocities, within limits, a desirable feature. Probably penetration of air into the coke column is over em-

Table XII

CUPOLA MELTING FACTORS

Melting capacity tons per hour	Internal diameter inches	Speed of fan R.P.M.	Pressure of air inches H_2O	Horse-power
0.5 to .75	15	4800	10	1.5
0.75 to 1.25	16	4700	12	2.5
1.25 to 1.75	18	4100	12	3.75
1.75 to 2.5	20	3700	14	5.75
2.5 to 3.5	26	3200	14	7.5
3.5 to 4.75	29	2900	16	12
4.6 to 6	35	2750	16	15
7 to 9.5	41	2300	18	27
10 to 14	53	2100	18	40
13 to 17	70	1850	20	50
17 to 23	80	1675	20	66

phasized even in large diameter cupolas. Lower pressures recommended are typified in Table XIII, and are expressed both in inches of water and ounces per square inch.

A more satisfactory comparison of the penetrating power of the blast is to be had by a comparison of the kinetic energy. This has the advantage of directly relating the penetrating power of the blast to its velocity. Kinetic energy of blast per cubic foot can be calculated from the formula:

KE=

$$\frac{\text{(Density of blast per cubic foot) (at blast temperature and pressure)} \times \text{(Velocity)}^2 \text{ (F.P.S)}}{2 \times 32.2} \text{ foot-pounds}$$

A comparison of the penetrative force under various conditions can be made by the use of the relation:

Penetrative force=

$$\frac{\text{(KE per cubic foot of blast)—pounds}}{\text{(radius of melting zone in feet)}}$$

Velocity of gases under given conditions in the cupola stack will be proportional to the volume of air delivered and to the area of free passages in the stock. This area under given con-

Table XIII

SUITABLE BLAST PRESSURE

Diameter inches	Ounces per square inch	Inches water
36 to 48	9	15.5
24 to 36	8	13.8
48 to 60	10	17.25

ditions will be constant. Various assumed values between the limits of 0.42 to 0.25 times the cross sectional area of the cupola have been used in calculation. These values obviously depend on the character of the coke used.

Calculations on velocity of gases passing through the cupola stack vary considerably according to the value taken for the area of passages between the coke. Normal stream velocity of air delivered is increased in the passage up the stack by increase in volume of the gases due to their expansion under heat influences. Gases are claimed to expand to about 7 times their original volume and under these conditions the blast velocity is then

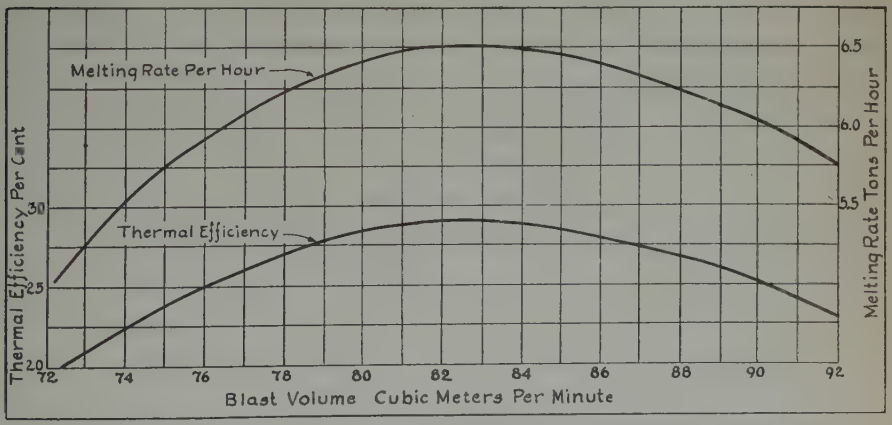


FIG. 83—CHART SHOWING BLAST VOLUME AND EFFICIENCY RELATION

about 100 feet per second. Other observers give values of from 100 to 110 feet per second, and recommend that to avoid further rise in velocity the shape of the lining should be flared out out to approximately 1.25 times the area at the tuyere level.

In common practice the melting rate of a cupola is related to the cross sectional area. Under normal conditions the amount of fuel consumed generally bears a simple relationship to the cross sectional area. This rule holds for all types of shaft furnaces. With blast pressures, quantities and temperatures in common use in cupolas from 1.0 to 1.1 pounds of coke are burned per square inch per hour. On the assumption of an average coke ratio of 1 to 10 this rate of burning is equivalent to a melting rate of 10 to 11 pounds per square inch cross sectional area. This basis is somewhat arbitrary but it is the common rule for determination of the nominal melting rate of cupolas. As a purely nominal rule it is quite satisfactory. It is a simple ratio to remember and bears a resemblance to similar rules in common use in general furnace construction.

Actual melting rate depends upon efficiency of generation of heat and efficiency of transmission of this heat to metal constituting the charge. An extension of the simple rule has been devised in which the melting rate is related to the coke efficiency. This rule is expressed in the formula derived as follows, where M = the melting rate in tons per hour; D = the diameter of the cupola in inches; P = the percentage of coke to iron by weight. Then

$$M = \frac{11\ D^2 \times 1 \times 100}{4 \times P \times 2240}$$

$$= \frac{D^2 \times 100}{2851 \times P}$$

$$= \frac{0.0351 \times D^2}{P}$$

In his experiments many years ago F. J. Cook considered the observed melting rate in relation to the cupola diameter. He

defined the maximum successful melting rate as the rate of melting unaccompanied by oxidation. The diagram Fig. 82, is plotted from the former relation and at a glance shows nominal melting rates for various diameters and coke ratios.

Extensive experiments of Piwowarsky and his collaborators demonstrate that the maximum melting rate is coincident with the maximum thermal efficiency as shown in Fig. 83.

CHAPTER VII

Tuyeres

Tuyere area—Blast main and wind belt—Shape of the lining—Height of the cupola—Size of metal and coke charges—Depth of furnace well—Summary of details—Temperatures attained in the cupola.

IMPROVED efficiency of the modern standard cupola is due entirely to the dimensional relationship of the various parts. Dimensional relationships involve shape and proportions of internal form of the cupola, total area and number of tuyeres, pressure, volume and velocity of the air supply. All these can be varied extensively within the limits imposed by the standard shell. A wide diversity of opinion obtains on many details and it is only possible in a work of this nature to record some of the more important and authoritative observations on the subject. Any rational system of cupola design obviously must be based on anticipated output. Melting rate, quantity, velocity and pressure of air supply have been referred to in the previous chapter and naturally lead to consideration of tuyere design, shape and effective height of the lining, well capacity and other proportions.

Usually the tuyere area is considered in relation to the cross-sectional area of the cupola at the tuyere level. Recommended ratios of tuyere area to cupola area, number of tuyeres and shape vary in almost every conceivable manner. For example, Cook recommends that the tuyere area for general work should be 1/9, and for special cylinder work 1/12 to 1/16, the cross-sectional area of the cupola. This is much smaller than tuyere sizes prevailing today in which the tuyere area usually is about 1/5 of the cupola area at the tuyere level. Slightly smaller, also slightly larger ratios than this frequently are recommended. With the idea of obtaining somewhat higher pressures a tuyere area of 17.5 per cent of the cross-sectional area is recommended for larger diameter cupolas. For smaller diameter cupolas ranging from 24 to 36 inches a tuyere area of 25 per cent or ¼ of the cross-sectional area at the tuyere level is allowable. Foundrymen now generally agree that extra tuyeres in addition to the

regular single row are not necessary, providing the requisite quantity of air is passed through the cupola. A single row of tuyeres passing the correct amount of air effects a distinct saving in the height of bed coke. This view has not yet gained the adherence of all foundrymen and the majority of standard cupolas are fitted with at least two rows of tuyeres. Melters who prefer a single row, easily can close the second row.

The type of tuyere in which the air is expanded on entering the cupola has been adopted almost universally. The tuyeres may be either rectangular or circular in cross-section, expanding toward the cupola to twice the area at the entry. This type of tuyere has a high discharge coefficient. Compared with the parallel nozzle, the respective coefficients are 0.92 and 0.50.

Modern tendency in tuyere design is to admit air at all points around the circumference at the tuyere area, a tendency which has the advantage of maintaining the tuyeres comparatively close to the bottom and consequently holding the coke low in the bed charge. Various methods of arranging the tuyeres tangentially to the circumference have been abandoned almost completely in standard cupola design.

Y. A. Dyer, in an excellent summary of American cupola practice states that the ratio of the tuyere area should decrease with increase of cupola area, in proportion to the size of the cupola. That is the tuyere area of a 24-inch cupola may be 20 per cent of the cupola area, while in a 90-inch cupola the tuyere area may be only slightly more than 12 per cent. He gives the ratio of combined tuyere area to cupola area in a range of fractional graduations as follows:

Cupola Diameter	Tuyere Ratio
24-42 inches	1:6
44-62 inches	1:7
64-90 inches	1:8.3

According to Dyer the ratio of tuyere area to blast pipe area is exactly the reverse of ratio of the former to cupola area. That is; the blast pipe area of a 24-inch cupola may be practically 56 per cent of the tuyere area, while in a 90-inch cupola, the blast

pipe may be 92 per cent of the tuyere area. The following relationships are given by another investigator:

Cupola Diameter	Ratio of Blast Main area to tuyere area
Up to 42-inch diam.	1:1.6 to 1:1.75
42-inch to 63-inch diam.	1:1.4 to 1:1.6
Larger diameters	1:1.1 to 1:1.4

Object of providing a larger area of blast main than the tuyere discharge nozzles is to counteract losses due to friction.

The wind belt also should bear a definite relation to the blast main and it is recommended that the ratio of sectional area of wind belt to that of the blast main should not be less than 3:1 and may be 3.5:1 or 4:1 in large cupolas. According to many designers the cubical contents of the wind belt should equal one second's air supply for the cupola.

The results given in Table XV are abstracted from data

Table XIV

SUGGESTED DATA FOR DESIGNING OR REMODELING A CUPOLA

Cupola lined diameter in.	Height bottom to charging door ft. in.	Tuyeres No.	Tuyeres Size : in.	Blast pipe diameter in.	Wind-box size in.
24	9 0	5	3 x 6 x 14	8	6 x 25
26	9 6	5	3½ x 6 x 15¼	8½	6 x 28½
28	10 0	5	3½ x 6¾ x 16½	9¼	6¼ x 32¾
30	10 6	6	3¼ x 6¾ x 14¾	10	6½ x 36
32	10 6	6	3½ x 7 x 15¾	10½	6¾ x 38⅛
34	11 0	6	3½ x 6¾ x 16⅞	11⅛	7 x 42
36	11 0	7	3½ x 7¼ x 15⅛	12	7½ x 44⅛
38	11 6	7	3¾ x 7¾ x 16⅞	12¾	8 x 47
40	11 6	7	3¾ x 8¼ x 16⅞	13¼	8½ x 48¼
42	12 0	7	4 x 8⅜ x 17⅛	13⅜	9 x 50
44	12 0	8	3¾ x 8⅜ x 16¼	14½	9½ x 52
46	12 6	8	4 x 8½ x 17¼	15⅛	10 x 54
48	12 6	8	4 x 9 x 17⅛	15¾	10¼ x 56¾
50	13 0	8	4 x 10 x 18½	16½	10¾ x 59½
52	13 0	10	4 x 8 x 15¼	16¾	11 x 60
54	13 6	10	4 x 8¾ x 15⅞	17⅝	11¾ x 62½
56	13 6	10	4 x 9¼ x 16½	18¼	12 x 65½
58	14 0	10	4 x 9⅜ x 17¼	18⅞	12¼ x 68¼
60	14 0	10	4 x 10¼ x 17⅞	19⅝	13 x 69½
64	15 0	11	4 x 10½ x 17¾	20⅞	14¾ x 69½
66	15 6	11	4 x 10⅞ x 17⅞	21½	15½ x 70
68	15 6	12	4 x 10½ x 17½	22¼	15¾ x 75
72	16 0	12	4 x 11½ x 17⅞	23⅝	16 x 80⅛
78	17 0	13	4¾ x 10 x 17⅞	25⅝	16 x 96¾
80	17 0	14	5 x 9¼ x 16⅞	26⅜	16½ x 99
84	17 6	14	5 x 10 x 17¾	27¾	17 x107
90	18 6	15	5 x 10½ x 17⅞	30	17 x124⅝

given by Dyer and are typical of American practice in this respect.

In a previous chapter dealing with velocity of gases in the cupola stack a slight flaring was recommended from the tuyere level to the top of the melting zone. Advantage claimed was that

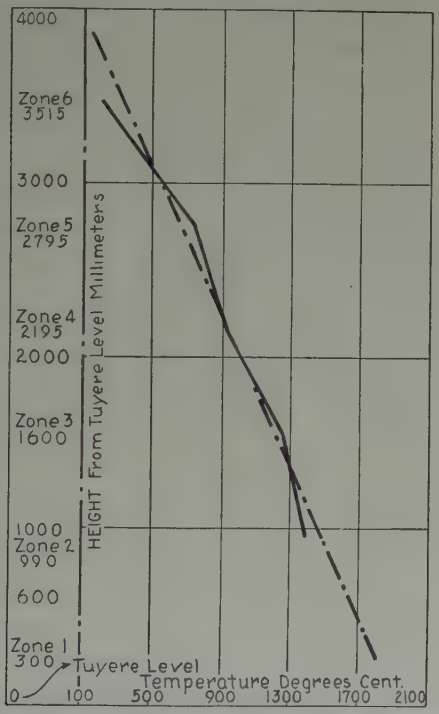


FIG. 84—TEMPERATURE MEASUREMENTS AT VARIOUS LEVELS

exit of the gases was retarded slightly. Gain from this probably is small over that of a definitely parallel lining.

Effective height of the cupola is measured from the top of the tuyeres to the charging door and since this is the main dimension in determining the period of contact between the hot gases and the charge, it is of major importance. Limit to the height principally is determined by the carrying capacity of coke in the bed. With more extensive adoption of mechanical charging the

cost of raising the materials to the charge level, formerly a consideration which determined the height of cupolas, is not now so important and can almost be eliminated from consideration.

A. Wagner, *Die Giesserei,* May 17, 1924, found that by increasing the ratio of the effective height of the cupola, i. e., from the tuyere level to the bottom of the charging door, to its diameter, the temperature of the waste gases fell to 280 degrees Fahr. He deduced the formula $Ht=6.5\ D$ where Ht is the height from

Table XV

RATIO OF TUYERES, BLAST MAIN AND WIND BELT

Cupola Diameter	Tuyere area	Blast main diam.	Blast main area	Wind belt area	Ratio
32 inches	149 sq. in.	10½ inches	86	261	3:1
36 inches	180 sq. in.	12 inches	113	336	3:1
44 inches	.....	12½ inches	143	389	2.7:1

the tuyere level to the charging door.

A formula of American origin based on the distance from the cupola bottom to the charging door sill is given as $Hb=2D+5$ feet where Hb is the height in feet from the hearth level to the charging door and D is the diameter of the cupola at the tuyere level, also in feet. Values obtained from this formula are lower than from most of the others mentioned.

The theoretical considerations in determining the effective heights of cupolas have been developed extensively by M. Karnaukhov and have been described in *Iron & Steel Industry,* December, 1928. A quadratic expression is deduced relating the effective height of the cupola to the diameter and the thermal efficiency. From the constants derived in the manner indicated the following relations are obtained: H (common)$=3.345\ D$, H (maximum)$=7.93\ D$.

Height equivalent to four or five times the diameter at the tuyere level is the common rule in design. From considerations of the velocity of the blast, a relationship of 20 to 24/D has been deduced between the height and diameter. In larger cupolas this relationship gives height values considerably lower than are in common use and have been found advantageous in practice. In a formula deduced by Buzek, the effective height H of the cupola

is assumed to be the height from the top of the melting zone to the charging door or the top of the charge level. Height of the melting zone *Hs* is calculated as 0.5*D* where *D* is the diameter of the cupola. The bottom of the melting zone, of course, is the tuyere level. The height *H* is determined by the following relation:

$$H=4/Q\ (1-0.05K) \quad \text{..... (1)}$$

where

Q=cross sectional area of cupola in square feet.
K=quantity of coke for 100 pounds of iron.

$$Q=\frac{D^2 \times \pi}{4} \quad \text{..... (2)}$$

$$H=3.55 \times D\ (1-0.05K) \quad \text{..... (3)}$$

For quantities of charge coke of from 6 to 12 per cent, the value of $0.05K=0.3$ to 0.6 and the relation then becomes:

$$H=4.6D \text{ to } 5.67D \quad \text{..... (4)}$$

For comparison with the usual method of expressing the height from the tuyere level to the charging door, the height of the melting zone 0.5 *D* must be added, the height of the melting zone $Hs=0.5\ D$ must be added to equation 4. The final relationship expressing the height *Ht* in the usual terms, for charge coke percentages of 6 to 12 per cent becomes:

$$Ht\ 5.1D \text{ to } 6.17\ D \quad \text{..... (5)}$$

This is close to the ratio given by Pfeiffer—in which it is stated that the height should be six times the cupola diameter at the tuyere level—and checks his statement.

Dyer states the height of small cupolas should be at least sufficient to receive 6 to 8 feet of stock before starting the blast. Medium cupolas should hold 9 to 10 feet of stock and large cupolas 11 to 14 feet. From the foregoing it is apparent that the ratio of height to cupola diameter, where tuyeres are located 16 to 18 inches above the bottom, may vary from 4.5:1 to 3.4:1 in small cupolas; 3.4:1 to 3.8:1 in medium cupolas; and 2.8:1 to 2.4:1 in large cupolas used for continuous melting with low tuyeres, 6 to 8 inches above the bottom. Height of the door may be raised 6 to 8 feet for small cupolas and 10 to 12 feet for larger

sizes. Height need not be so great on smaller cupolas by reason of relatively lower gas velocities.

General rule for weight of cupola metal charges is about 1/10 of the melting rate per hour in pounds. Kleinsorge in *Die Giesserei*, 1926, No. 26, page 561, measured the height of the coke charge of a great number of cupolas and determined the CO_2 and CO content of the gas current. He found the most suitable height to be 0.59 foot. The weight of the coke charge then is calculated according to the following formula

$Pc = \frac{\pi}{4} D^2 hR = 0.463 D^2 R$, where Pc = weight of the coke charge, cwts.; D = diameter of the shaft, feet; H = height of the coke charge = 0.59 foot, and R = weight of the coke per cubic foot.

Weight of coke per unit volume largely depends upon the diameter of the shaft, because toward the periphery the coke is heaped more loosely than in the middle. Results of experiments undertaken in this direction are recorded in the following table:

Diameter of Shaft Feet	Coke charge per cubic foot Cwts.	Standard Coke weight Cwts.
2.624	0.178	0.54
3.116	0.238	1.07
3.28	0.259	1.29
3.51	0.269	1.54
4.1	0.276	2.15

Values are plotted in Figs. 85 and 86. Only a fixed amount of iron can be melted and superheated with the standard coke weight. Iron for heavy and medium weight machinery castings can be melted with 8 to 9 per cent coke without any difficulty, whereas light and thin-walled castings demand 10 to 12 per cent.

Depth of the furnace well in practice is measured as the distance from the hearth bottom to the lower edge of the slag hole. The slag hole itself usually is arranged from 5 to 10 inches below the level of the bottom tuyeres and should be located below a point midway between two tuyeres. This arrangement prevents the blast from cooling the slag. Depth of the well largely is de-

termined by the quantity of iron to be collected and the hourly melting capacity of the cupola. Minimum depth is desirable in cupolas fitted with a forehearth or where the tap hole is maintained open constantly. A deep well increases the difficulty of maintaining hot metal.

Temperature attained in cupola melting has aroused some

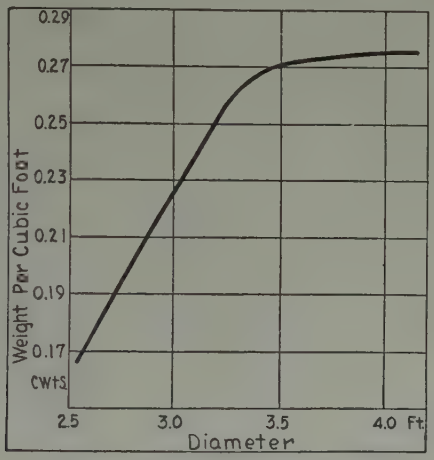


FIG. 85—WEIGHT OF COKE VARIES

discussion and interest among foundrymen. Experimental determination of temperature at different levels in the cupola has been attempted on many occasions. Belden, in 1913, came to the conclusion that all these attempts failed. Use of platinum-rhodium thermocouples failed through the fracture of the couples due to the weight of the moving charges. At a level 6 inches above the top of the tuyeres the fireclay protecting tubes and fireclay ends on water-cooled tubes melted rapidly. This gives some indication of the high temperature in these zones. The maximum single result of temperature obtained by Belden at this plane was 3083 degrees Fahr. (approximately 1700 degrees Cent.). This result was obtained through an optical pyrometer. Results obtained by Piwowarsky and Meyer by a similar type of pyrometer are plotted diagrammatically in Fig. 84.

Extrapolation of this curve to the tuyere level indicates tem-

peratures of at least 1700 degrees Cent. and under these conditions the maximum tapping temperature of the metal never exceeded 1445 degrees Cent. There is no *a priori* reason to expect the tapping temperature to be equal to the maximum temperature obtained in the cupola stack. In fact there is every reason to expect the tapping temperature of the metal to be lower than this. Rawlinson states that the temperature of the metal at the

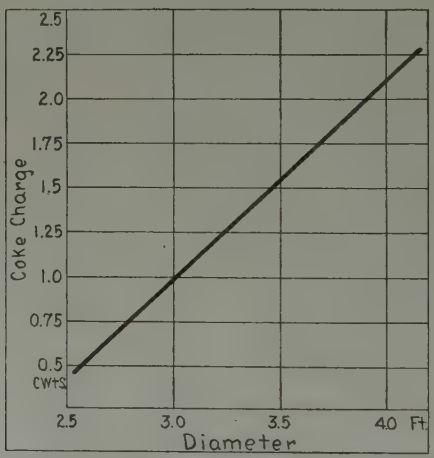


FIG. 86—COKE CHARGE BASED ON DIAMETER

tapping spout varies from 1250 to 1355 degrees Cent. He doubts if the temperature ever rises much over 1400 degrees Cent.

CHAPTER VIII

Specials

Increase efficiency—Special construction—Cameron cupola—Ronceray cupola—Blakeney cupola—Corsalli cupola—Hot blast cupola—Schurmann cupola—Introduction of secondary air—Stewart cupola—Greiner cupola—Poumay cupola—Possibility of economy by hot blast or secondary air injection—Auxiliary powdered coal—Auxiliary oil—Water injection—Wuest oil fired refining furnace—Inclined cupola.

PATENT literature of the world has been enriched by at least a dozen patents annually for a number of years, concerning either minor modifications or radical alterations with the object of improving the working, efficiency and economy of the cupola. Attempt to describe even a few of the various proposed modifications is quite impossible.

Attempts to improve cupolas fall into two main groups (1) Improvement in detail design to meet special construction or production conditions. (2) Improvement of overall efficiency. No distinct line of demarcation exists between these two groups. Almost invariably any alteration whatsoever is claimed to increase the efficiency. Claims for 25 to 30 per cent fuel economy combined with low sulphur content in the iron are circulated freely.

Detachable wells and slag separating devices dealt with in previous chapters fall in the first group. A recent British patent No. 175207 by C. E. Taylor covers a tangential tuyere arrangement and a specially shaped wind belt. Construction, illustrated in Fig. 95, shows the usual channel shaped wind belt, eccentrically disposed in relation to the cupola shell in such a manner as to gradually decrease the cross sectional area from the air inlet. The object of this construction is to obtain a uniform pressure at all points in the wind belt. Gradual constriction of the wind belt area presumably is proportional to the pressure losses due to friction and other causes.

Special cupola construction, illustrated in Fig. 94, manufactured by the Constructional Engineering Co. Ltd., is due to Cameron. It bears considerable resemblance to the original Ireland

cupola. The wind belt is embodied within the lines of the shell. A single row of tuyere openings forms practically a continuous tuyere on the inside. Efficient melting and fuel economy are claimed for this construction.

Another special construction due to Levoz is described in a

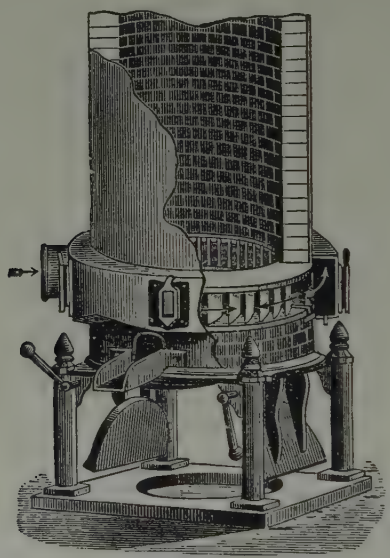


FIG. 87—SECTIONAL VIEW OF BLAKENEY CUPOLA

recent British patent No. 187577. The Ronceray cupola is remarkable for its extreme simplicity. A simple cylindrical shaft entirely devoid of the usual column supports is suspended from the charging floor framework. Fig. 36, reproduced in Chap. III, shows the Ronceray syphon brick and drop bottom. Dispensing with the columns is claimed to facilitate all work in the vicinity including cleaning up after the heat.

Kirk describes a reversion to the rectangular form in the Peevie cupola. Small sizes were square in cross section and the larger sizes were rectangular. Increase in capacity was obtained by extending the long side of the rectangle. Kirk states this construction was peculiarly liable to bridging.

The Blakeney cupola equipped with tangential tuyeres, de-

scribed by Kirk and illustrated in Fig. 87, is stated to have given every satisfaction.

Special adaptation of the ordinary cupola to receive additions of ferrosilicon and ferromanganese to the molten metal lying in

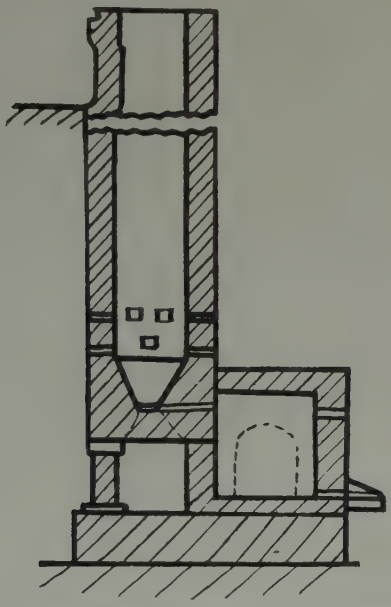


FIG. 88—PIWOWARSKY CUPOLA WITH RECEIVER

the hearth of the cupola or in a receiver is the feature of the so-called Corsalli process. Two forms of construction are illustrated in Figs. 91 and 92 showing the arrangements for use respectively without and with a receiver. Auxiliary melting apparatus takes the form of a pipe lined in the lower part with brick or other refractory material extending from the melting zone of the cupola to the extension of the cupola stack. A charging opening at the charging platform level is closed with a hinged door, a flap valve. Ferroalloys are charged through this opening in fairly large pieces preferably the size of a man's fist. A small admixture of charcoal is necessary, especially where the material is added in small pieces. Otherwise the material will cover the

small slit connection to the cupola and thus prevent the flame from entering the tube. Where the apparatus is used with a receiver, according to recommendation, the melted alloys flow direct through a slit connection into the receiver. It is claimed that a

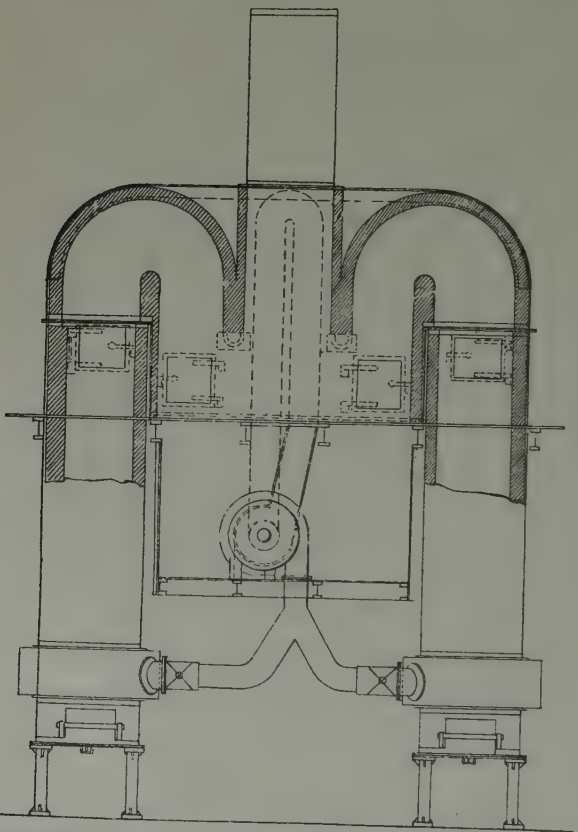


FIG. 89—HOT BLAST ARRANGEMENT APPLIED TO TWO CUPOLAS

temperature as high as 1600 degrees Cent. is developed in the pipe connection.

A special type cupola has been designed and patented by Piwowarsky for the express purpose of producing low carbon cast iron. The peculiar feature of this cupola diagrammatically rep-

resented in Fig. 88 is that the well is conical. It is claimed that the absorption of carbon is diminished in this cupola and further precautions can be taken by filling the well with graphite instead

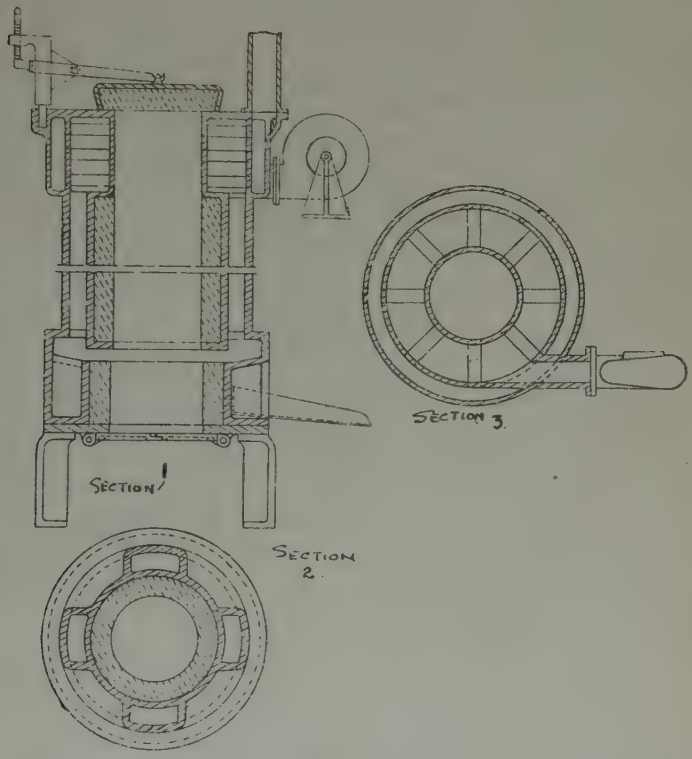


FIG. 90—TYPE OF HOT BLAST CUPOLA DEVELOPED BY SMITH

of coke.

Amount of heat lost through sensible and latent heat in the gases issuing from the throat of the cupola, naturally has prompted various proposals to divert this to actual melting operation. These various proposals fall into three classes. Those in which attempts are made to utilize the waste heat to provide hot blast. Those in which attempts are made, by the introduction of a secondary air supply, to burn the carbon monoxide formed in

the cupola. Various suggestions for the utilization of waste heat for such purposes as heating and drying ladles, molds and firing waste heat boilers.

Use of waste heat for auxiliary purposes preceded the at-

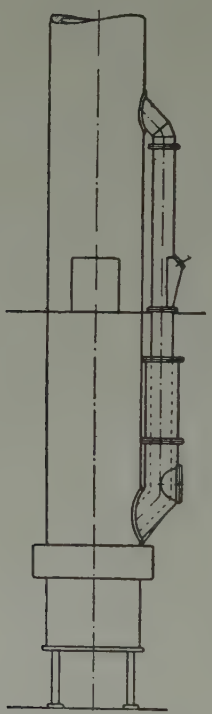


FIG. 91—CORSALLI MELTING APPARATUS WITHOUT RECEIVER

tempts at economy in other directions. Attempts at thermal economy rapidly were followed by attempts to utilize the waste heat as hot blast. Presumably the signal economies effected by hot blast in blast furnaces did much to inspire similar attempts with cupolas.

Various arrangements have been referred to in an earlier chapter. These included coils suspended in the cupola stack, economizer arrangement of pipes in separate brick chambers

through which the hot gases were led, pipes embedded in the brick lining, hollow shells. In all cases the air blast was conducted through pipes preheated by the outgoing gases. A portion of the heat in this manner was imparted to the blast and this hot blast in turn was expected to create higher temperature

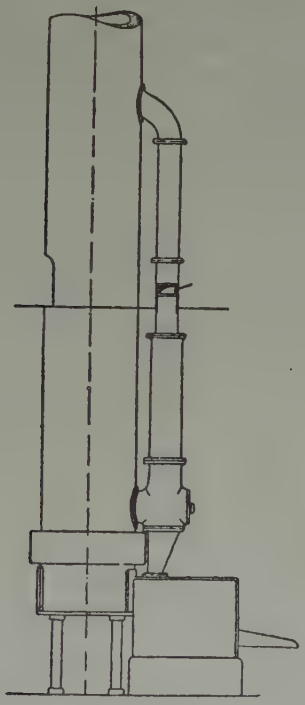


FIG. 92—AUXILIARY MELTING APPARATUS FOR RECEIVER TYPE CUPOLA

conditions in the cupola and consequently promote more rapid and economical melting.

One of the most modern attempts to revive the hot blast cupola recently has attracted some attention under the title of the Schurmann cupola. Of several other arrangements proposed, two are illustrated in Figs. 89 and 90. The design indicated in Fig. 89 is due to Roper (British patent No. 203757) in Fig. 90 to Smith (British patent No 239649). In both the method of

operation clearly is indicated in the illustrations. The Corsalli cupola is shown in Fig. 92.

The Schurmann cupola has been described as a side blast

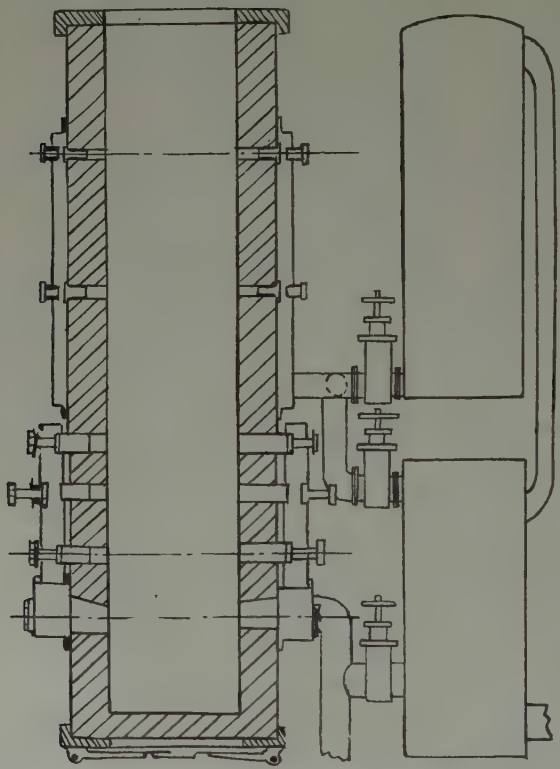


FIG. 93—ARRANGEMENT OF AUXILIARY TUYERES DESCRIBED IN GREINER AND ERPF'S ORIGINAL PATENT SPECIFICATIONS

cupola with reversing regenerators. Essentially, however, it may be regarded as a hot blast cupola, invented by the owner of a foundry at Coswig, Germany, who was granted the original German patent No. 266303. A typical diagram of the Schurmann arrangement, Fig. 97, shows two regenerator chambers erected alongside the cupola and connected to two sets of tuyere passages. The regenerator chambers are filled with checker brickwork as in open-hearth furnace practice. Upper extremities of

the regenerator are connected to a four-way reversing butterfly valve by which flow of ingoing air and exit gases can be reversed through either of the two regenerators. The blast enters the re-

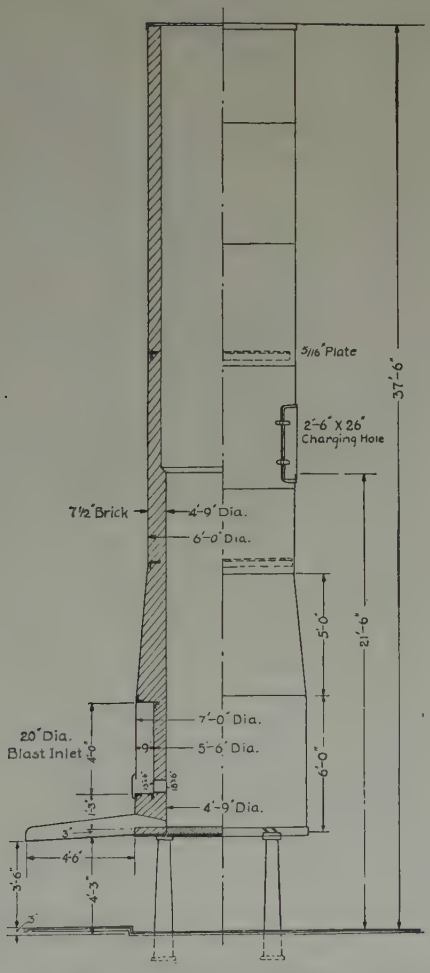


FIG. 94—RAPID MELTING CUPOLA PATENTED BY JOHN CAMERON

versing valve, passes through the regenerator and enters the cupola. The waste gases pass by the way of the tuyere openings into the regenerator and communicate a portion of their sensible

heat to the checker work, passing finally to atmosphere by way of the reversing valve and throttle valve into the chimney. In operation, the direction of the ingoing air is reversed every 10 minutes and as a result of passing through the regenerators heated by the passage of the outgoing gases during the period prior to the reversal, the air blast is injected hot into the cupola.

Cold air from the blowers is stated to be preheated to a temperature of 800 degrees Cent. in the regenerator and after passing through the cupola and the second regenerator, the gases

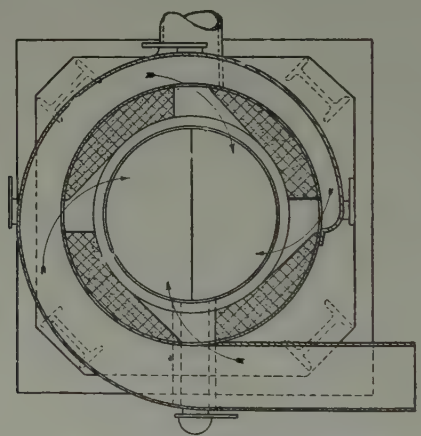


FIG. 95—TUYERES ARE SET AT A TANGENT AND THE WIND BELT GRADUALLY DECREASES IN SIZE

are discharged to the atmosphere at a temperature of 100 to 150 degrees Cent. Starting from cold, the regenerator is said to reach a temperature of 400 to 500 degrees Cent. in 15 minutes. The makers claim that with this cupola the charge coke is reduced by 25 per cent and a consequent reduction in the sulphur content of the metal. It is stated that up to October, 1925, the arrangement has been fitted to about seventy cupolas in German foundries. In England and the United States, this arrangement has been tried on several cupolas, and so far as the author's knowledge goes it has been abandoned.

A further recent attempt by the Griffin Wheel Co., Chicago, to provide hot blast has been described in *The Foundry*, Sept. 15, 1926, page 729. A similar saving of about 25 per cent in the

fuel consumption is claimed. It is stated that out of 60 per cent of the gases of combustion passing up the stack in the ordinary way, 40 per cent is drawn off by the exhausting fan from a wind belt encircling the cupola about 2 feet below the charging door.

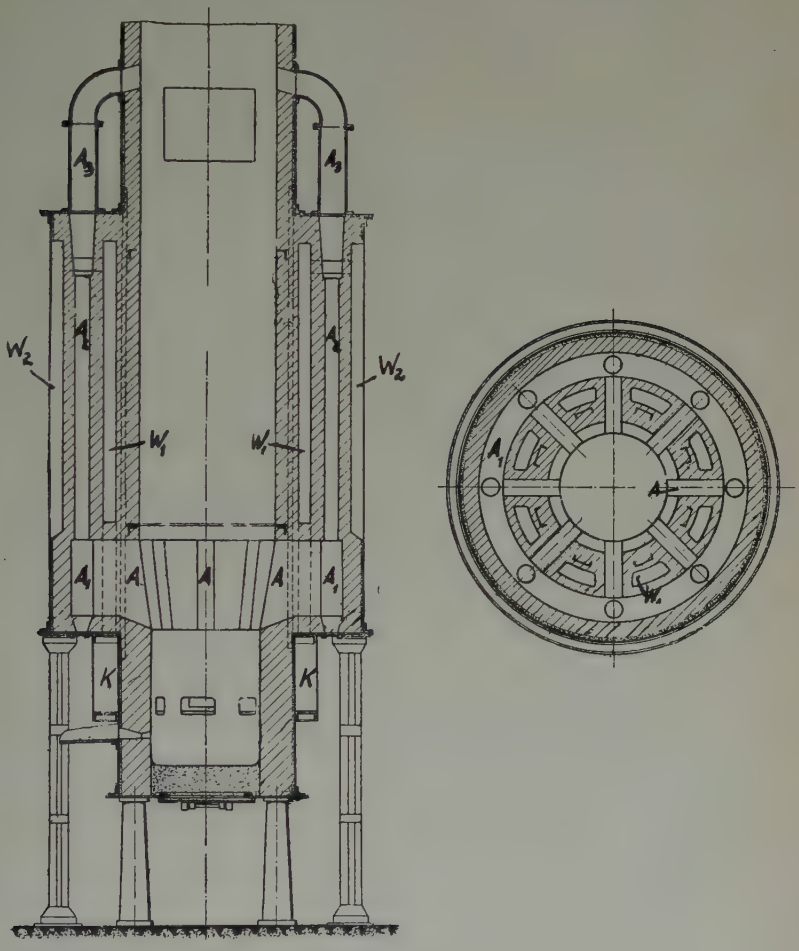


FIG. 96—HOT BLAST CUPOLA DESIGNED BY HAMMELRATH

Gases withdrawn by the fan naturally contain a little carbon monoxide. They are passed through a down pipe to a combustion chamber where the carbon monoxide is burned with the ad-

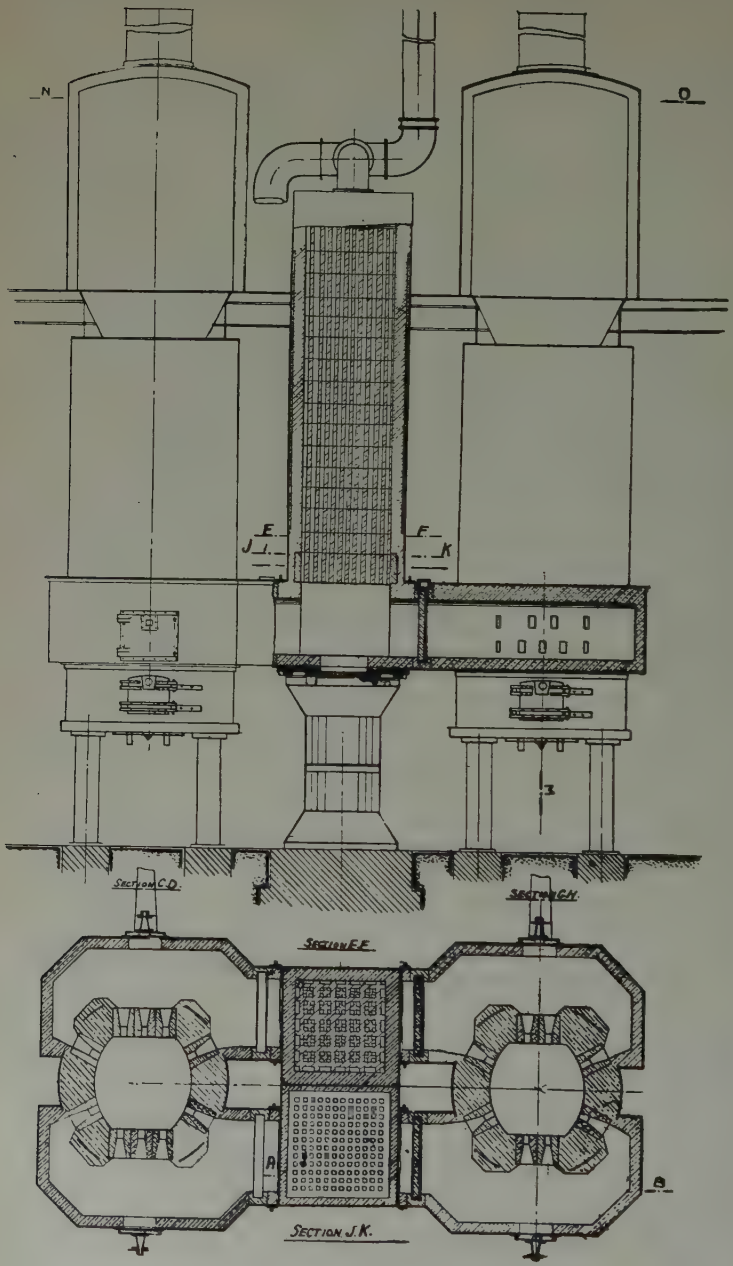
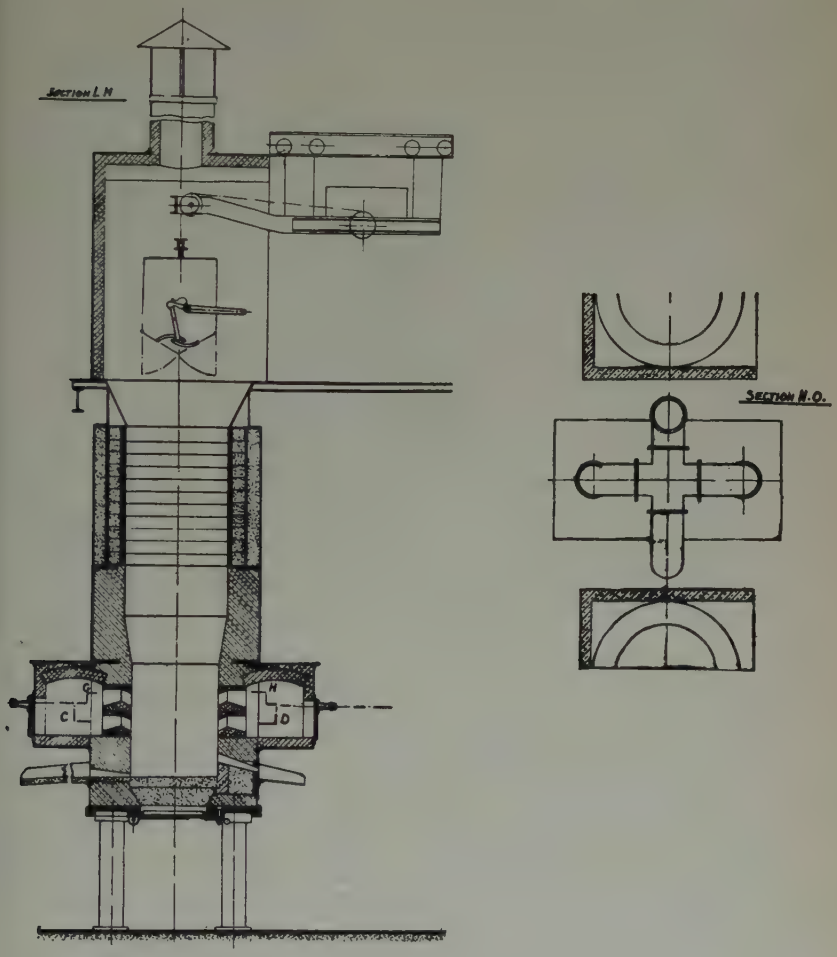


FIG 97—GENERAL ARRANGEMENT AND SECTIONAL VIEWS OF SCHURMANN HOT BLAST CUPOLA. THE VERTICAL SECTION AND SECTION OF DOWN COMER PIPES ARE SHOWN ON THE FOLLOWING PAGE

dition of secondary air. Sensible heat contained in the gases and heat resulting from combustion of the carbon monoxide is transferred to the blast by passing the hot gases through a chamber containing a battery of cast iron pipes. The blast passing



through this chamber absorbs heat and is delivered to the cupola at a temperature of 300 degrees Cent. This arrangement applied to a 74-inch diameter cupola is stated to have been in successful

operation on a production basis for about 2 years, melting from 20 to 21 tons per hour for 6-hour runs each working day.

In another ingenious design of hot blast cupola, illustrated in Fig. 96, the preheater is built around the cupola shell and is heated by the hot waste gases directed by the specially formed passages A_1 above the upper limit of the melting zone into the passages A_2 and thence by way of A_3 into the stack. The incoming air is led through this preheater by way of W_2 and W_1 to the wind belt K.

Attempts to recover latent heat by the injection of secondary air to burn carbon monoxide inside the cupola are fairly familiar. Introduction of two rows of tuyeres by Jonathan Ireland probably was the first attempt. Ireland was followed at a later date by D. Y. Stewart, who introduced secondary air by auxiliary tuyeres at a series of different levels above the normal tuyere level. Probably this cupola was the origin of the standard Stewart rapid cupola which for a long time was equipped with only three rows of tuyeres. Change from five rows in the original Stewart cupola to three and later to two rows in the modern standard Stewart rapid cupola typifies a gradual change in opinion regarding the extra rows of tuyeres.

Considerable prominence has been given the original Stewart arrangement and later Greiner and Erf construction through revival of a similar construction recently under the title of the Poumay system. The Greiner construction has been illustrated previously. This new construction similar to that given by Kirk, Rhead and others, presents auxiliary tuyeres spirally disposed around the cupola stack. The cupola differs from Greiner's, illustrated in the British patent No. 6939/1885 in which additional tuyeres in three horizontal rows were fed by three ring mains connected to the main wind belt. This arrangement in many respects was similar to one which came under the writer's charge some years ago, and which is illustrated in Fig. 93.

In the recent Poumay arrangement, British patent No. 232630, the auxiliary tuyeres are arranged in spiral fashion, directly and individually connected to the main wind belt with a regulating valve to each tuyere. Special form of tuyere in the

upper of the two normal rows also special form of the two principal rows of tuyeres are illustrated in Fig. 99.

According to Kirk, claim of saving at least 20 per cent fuel was made for the Greiner cupola. In some instances it was stated that the fuel saving reached 40 and even 50 per cent. At one time, over three hundred of these cupolas were in use in Europe.

Claims for the Poumay system include the ability to melt high phosphorus iron with 6 per cent of melting coke against 9

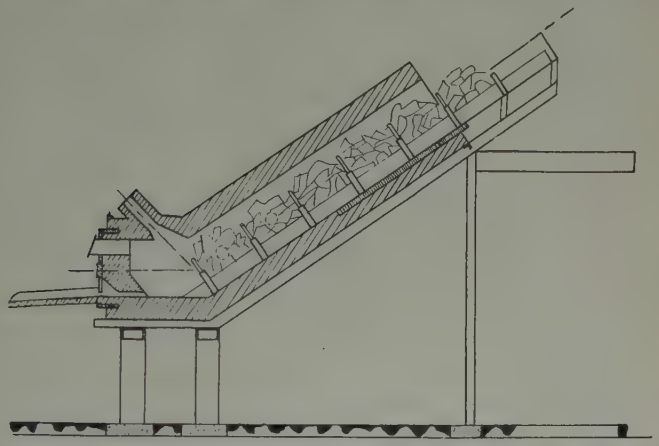


FIG. 98—INCLINED CUPOLA INVENTED BY L. J. ROCHLITZ FOR OPERATION WITH LIQUID OR GASEOUS FUEL

to 14 per cent used in ordinary practice, and to melt hematite with 8 per cent against the usual 12 to 18 per cent. The owners claim to be able to melt all steel charges with 12 per cent of melting coke, to invariably obtain hot metal, diminished losses in silicon, manganese and total metal and a diminution in the carbon pick-up. The Poumay principle can be applied to existing cupolas or incorporated in new cupolas to deal with specified outputs.

Proponents for all these systems of secondary air injection claim that their economy is due to the combustion of carbon monoxide at the higher levels of the cupola by the aid of this secondary air. Heat generated by secondary combustion is communicated to the charge which thus is melted with a lower total coke consumption, it is claimed.

Before referring further to types of special cupolas a brief consideration of economical possibilities arising out of the use of

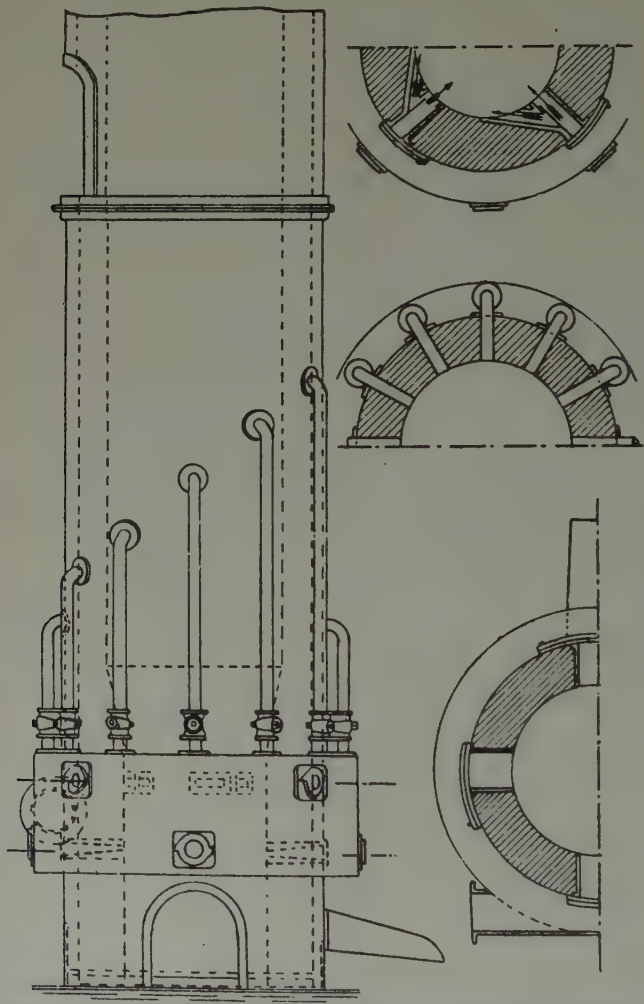


FIG. 99—POUMAY SYSTEM OF SECONDARY AIR INJECTION THROUGH SPIRAL ROW OF SMALL OPENINGS

hot blast or secondary air injection may be useful. This has been considered partially in previous chapters.

Hot blast and secondary air injected with the object of burn-

ing the CO *in situ* are the only two methods which have been tried for recovering or partially recovering sensible and latent heat carried away by outgoing gases in normal standard cupola practice. Whether any of this heat actually is recovered by these various methods unfortunately has not been demonstrated clearly in every instance. For that reason the theories underlying the various proposals are still the subject of much controversy. The only method of forming a just estimate of economy directly resulting from application of hot blast or secondary air is by a strict comparison of the overall thermal efficiency of these special cupolas with the best thermal efficiencies obtainable with normal types and operation.

Comparison of coke ratios only, without reference to ash content, molten metal temperature, temperature and composition of the outgoing gases is insufficient. Authenticity of some of the coke ratios obtained or claimed for these special cupolas often is subject to grave suspicion.

In England where this is written, some of the best ratios obtained are no better than can be obtained in the best normal practice under similar conditions of melting temperature and ash content. Low coke ratios appear to be possible from scientific determination of the most economical conditions in standard cupolas. The fact that coke charges in many foundries still are left to the personal judgment of the cupola attendant raises the question at once, "Are our coke ratios too high?" Conceivably even today, careful analysis of normal cupola practice will be repaid by a still further saving in coke.

Theory of thermal economy by the injection of secondary air through auxiliary tuyeres rests on a fallacious basis. Possibility of burning CO to CO_2 in this manner is undoubted, but this conversion is accompanied immediately by an increase in temperature to such an extent that the CO is reformed at the still higher levels. This was the author's experience with the arrangement previously illustrated. Operation with a lower coke consumption than normal, was accompanied by a lower metal temperature and melting rate. So far as the author is aware, determination of the thermal efficiency of a cupola operating with secondary air tuyeres never has been made.

Possibilities of hot blast are restricted by the intermittent working of the majority of cupolas. Any cupola designed for hot blast operation must operate as a cold blast cupola for a portion of its run. Possibility of economy under such conditions will be influenced to a great extent by the proportion of time in which the hot blast is operating under optimum conditions. Any improvement in thermal efficiency ultimately must be considered on an economic basis and only can be justified if the saving result-

Table XVI

LEADING DIMENSIONS

Inner diameter of the furnace, ft.	2.95
Area of the furnace, sq. ft.	6.85
Total height of the stack, ft.	19.36
Number of blast tuyeres	4
Area of blast tuyeres 1.21 X 0.59 ft. = sq. ft.	0.71
Total area of blast tuyeres, sq. ft.	2.84
Distance between tuyere level and hearth level, ft.	4.13
Active height of the furnace, ft.	15.22
Active height of the furnace / Diameter of furnace	5.15
Area of blast tuyeres / Area of furnace (1:2.4)	0.42
Number of powder tuyeres	3
Area of powder tuyere 0.69 X 0.39 ft. = sq. ft.	0.269
Total area of powder tuyeres, sq. ft.	0.807

ing from increase in efficiency is greater than the costs incurred in obtaining it. Probably many of the hot blast arrangements result in improved thermal efficiency under favorable circumstances, but up to the present, increased capital costs and increased maintenance costs have been too great to justify their continual use.

Other attempts to improve cupola economy differ from the foregoing. Instead of trying to recover the waste heat, the object is to reinforce the heat generated in the normal combustion zone. To obtain a larger evolution of heat per unit volume of combustion zone, or alternatively per unit of cross-sectional area of the cupola.

One of these methods depends on utilization of auxiliary powdered coal firing. A series of tests by Bardenheuer have been published in *Stahl und Eisen* 1927, page 1389, on the method introduced by Kaiser. In this process powdered coal to the extent of 0:8 to 1.0 per cent by weight of the iron charge, is injected through auxiliary tuyeres into the cupola by compressed air.

Dimensions of the cupola studied are given in Table XVI.

Distance of the coal powder tuyeres above the level of the blast tuyeres is of great importance. Where the distance is too great, CO forms for want of oxygen. Moreover, part of the

Table XVII

THERMAL BALANCE SHEETS OF COAL FIRED CUPOLA

In	First experiment Without auxiliary firing Calories	First experiment With auxiliary firing Calories	Second experiment Without auxiliary firing Calories	Second experiment With auxiliary firing Calories
(a) Iron charge	52,650	53,940	76,860	79,650
(b) Coke charge dry	8,399	5,424	13,179	8,648
(c) Moisture of coke charge	4,953	3,448	3,762	1,896
(d) Coal powder dry	.....	827	.....	1,039
(e) Moisture of coal powder	.....	36	.....	25
(f) Limestone	3,510	3,147	5,103	3,524
(g) Blast dry: Oxygen	34,940	25,149	57,901	44,145
Nitrogen	128,670	91,187	213,442	162,734
(h) Pressed air dry	.....	2,967	.....	3,713
(i) Moisture of blast	1,918	1,383	4,210	4,808
(k) Moisture of pressed air	.....	33	.....	78
(l) Combustion of carbon to carbon dioxide	15,147,891	13,325,148	15,248,979	13,269,177
Carbon monoxide	2,901,526	1,275,193	3,302,345	1,667,252
(m) Formation of FeO	85,812	71,226	108,392	84,810
(n) Formation of Mn.O	73,360	71,377	61,723	62,599
(o) Formation of SiO_2	1,152,970	1,187,549	1,233,224	1,056,514
(p) Formation of P_2O_5	113,679	79,182	16,802	4,766
(q) Formation of SO_2	14,366	17,581	24,542	9,533
	19,724,608	16,218,797	20,370,464	16,464,911

Out	First experiment Without auxiliary firing Calories	First experiment With auxiliary firing Calories	Second experiment Without auxiliary firing Calories	Second experiment With auxiliary firing Calories
(a) Molten iron	9,218,805	8,822,259	8,949,171	8,714,015
(b) Residual coke	60,043	74,311	53,480	60,655
(c) Slag	864,189	765,765	824,380	644,909
(d) Combustion gas: CO_2	1,152,119	1,009,565	1,154,424	986,024
CO	438,261	192,612	498,803	251,831
N_2	3,558,933	2,684,391	3,749,655	2,858,836
SO_2	1,296	1,586	2,214	860
(e) Evaporation of the charge coke moisture	330,192	214,002	161,208	75,825
(f) Evaporation of the coal powder moisture	.....	2,232	.....	981
(g) Dissociation of the limestone	533,775	445,498	504,292	324,989
(h) Loss	3,566,985	2,006,576	4,472,337	2,545,986
	19,724,603	16,218,797	20,370,464	16,464,911
Loss due to the formation of CO	6,730,589	2,958,029	7,658,357	3,867,478
Total heat income when combustion is complete	26,454,497	19,176,826	28,028,821	20,332,389
Burnt carbon from the fuel, kg	3,075.94	2,146.74	3,178.59	2,251.88
Heat income from the carbon when combustion is complete	24,915,114	17,388,594	25,746,579	18,240,288

powdered coal unburned escapes through the stack. If the distance is too small, the furnace output is lowered and the temperature of the iron remains unchanged. Best distance between the two levels for a cupola with an inside diameter of 2.95 feet, is 6.69 inches. Three powder tuyeres are provided and the pres-

sure of the air is from 36 to 42 pounds per square inch. Inner diameter of the air pipe line is 1.5 inches. Blast pressure in the main tuyeres is held low between 2.95 to 4.53 inches of water. Thermal efficiencies, metal temperature, and other data obtained by Bardenheuer in his tests are shown in Table XVII.

Auxiliary oil firing appears to have been suggested first by Bradley Stoughton, Bethlehem, Pa., and a description of equipment and process appeared in *The Foundry*, 1915.

Owing to the great scarcity of coke in Austria, experiments were undertaken to ascertain whether oil could be used in cupola melting. These experiments are described by Berthold in *Stahl und Eisen*, March 24, 1921. Three oil burners were used, and the number of tuyeres reduced to three. Somewhat less than the usual bed coke was charged, and the charge coke continued at 4 to 5 per cent. Oil consumption amounted to 1 per cent of the metal melted. Rate of melting increased 30 to 50 per cent, and the metal temperature remained unaltered.

Quite a new departure is embodied in the British patents No. 184479 and 183418 of the Vulkan-Werk of Duren. In this arrangement provision is made for a water spray, either above or below the tuyere level. Advantages claimed for this arrangement include hotter iron, reduced coke consumption, low sulphur content, and extension to the life of the lining of the cupola.

The Wuest oil fired refining furnace is described alternatively as a reverberatory or oil fired cupola furnace. Since the design includes a shaft in which cast iron is remelted, this furnace legitimately may be classified as a cupola furnace, although coke is not used as fuel. This furnace can be worked continuously like a cupola. Refined irons and irons of low total carbon content can be produced with certainty and with uniformity.

To some extent this special furnace resembles the duplex plant of a cupola and electric furnace which admittedly is the ideal type of plant in which to attain the special results mentioned. It is claimed for this plant that the results equal an electric furnace installation, but that this plant operating on oil fuel, obviates the expense of electric current.

Construction of the furnace is shown in Fig. 100. A re-

verberatory furnace hearth leads to a refractory lined shaft provided with a charging door at a higher level, exactly as in a normal cupola, and clearly shown in the section *E-F*. Continuation of the refractory lined shaft leads the hot gases into a preheat-

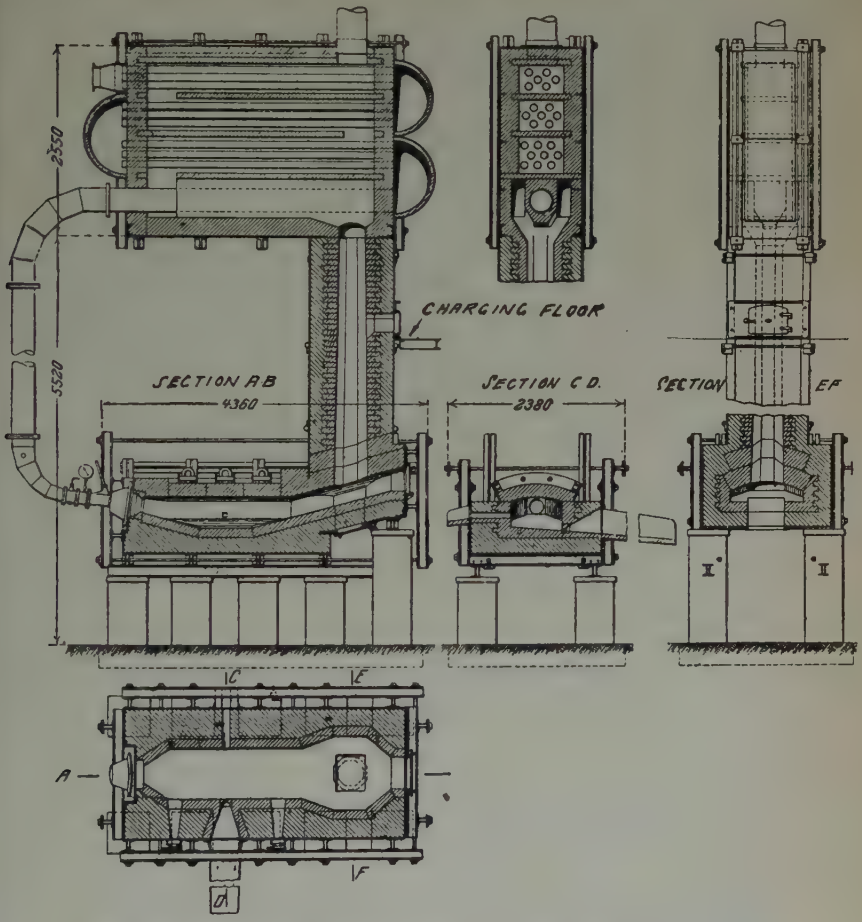


FIG. 100—SECTIONAL DRAWING OF A WUEST OIL-FIRED CUPOLA

ing device in which escaping heat is utilized to preheat the air for the oil burners. The preheater, clearly illustrated, consists of a large brick chamber, divided into four smaller chambers by refractory baffle floors arranged in a labyrinth. Air for the oil

burners is led through a series of tubes, in the top chamber and extending through one end wall into a domed connecting passage to a series of similar tubes carried in the chamber immediately below. From this chamber, the incoming air is led through the successive remaining chambers and is carried by a lagged pipe to the main oil burner at *A*, erected at the front of the reverberatory hearth directly opposite the shaft exit. Section *C-D* shows a cross section of the furnace through the slag and metal spouts.

Flame developed by the oil burner first sweeps the bath, where it strikes against the lower part of the column in the charging shaft. Material melts and runs down into the hearth, while fresh material is charged above or delivered through the throat opening. Escaping gases sweep through a preheater and heat the blast air on the counter current system. Blast temperatures, it is claimed, rise to 400 degrees Cent. and at times even to 600 degrees Cent. Slag flows from the side opposite the tap-hole. The shaft is easily accessible through a flap on the charging floor. Necessary repairs can be carried out quickly and conveniently through removable covers in the floor arch.

As in the cupola furnace, the charge is delivered from the charging stage with an addition of 1 to 2 per cent of limestone. No coke is necessary. Coal tar oil, with a value of about 9200 calories is used as fuel, and the temperature of the iron tapped out is between 1500 and 1600 degrees Cent.

Figures in the accompanying table also give particulars regarding efficiency of the furnace on a special charge with a melting point of about 1260 degrees Cent. These figures show low oil consumption and hourly output of a furnace which, of course, also can be built for larger outputs.

Total charge, kg.	4,500	4,200	4,000
Total charge, lb.	9,900	9,240	8,800
Output per hr., kg.	1,125	1,050	1,020
Output per hr., lb.	2,475	2,310	2,244
Oil consumption in preheating	1.1%	1.6%	0.87%
Oil consumption in melting	6.9%	8.7%	8.9%
Total oil consumption	8.0%	10.3%	9.8%

Gray cast iron melted by this method presents a low sulphur content, finer graphite separation, and the possibility of obtaining with accuracy a uniformly low carbon content of the particular analysis desired.

Another special form of cupola for operation with either liquid or gaseous fuel designed by Rochlitz (U. S. A. patent No. 1,476,106) is illustrated in Fig. 98. The shaft is inclined at an angle and the successive charges are carried in containers. Each charge may be melted separately and the patent specification describes a number of methods of controlling the movements of the charge.

CHAPTER IX

Blowers

Blowing apparatus—Positive pressure blowers—Roots blower—Baker blower—Centrifugal fan—Air measurement instruments—Measurement of pressure—Measurement of volume—The pitot tube—The venturi tube—The orifice plate—The Wilson-Crosby recorder.

TWO types of blowing apparatus are in common use today for supplying air at the comparatively low pressures required by the cupola. The two types are described respectively as positive pressure blowers and centrifugal fan blowers. In the former, the delivery of air by the machine is independent within limits of the resistance opposed to the air stream. In the latter the quantity of air delivered varies with the resistance offered. Fans are more sensitive to the effects of furnace obstruction. For large furnaces where considerable resistance is offered by the stock the positive pressure blower is favored by many. This distinction holds today with considerably less force than it did a few years ago. Almost universal adoption of electric motive power, developments in the construction of both centrifugal fans and motors during recent years have combined to make the fan a worthy competitor of the positive pressure blower even on large cupolas.

The reciprocating blowing engine or air forcing pump has given way entirely to the rotary type of positive pressure blowing apparatus for foundry cupolas. Three principal types of rotary blowers for this purpose are distinguished by the form and disposition of the impellers. The simplest type indicated in section in Fig. 101 consists of a cast iron casing *A*, provded with flanged inlet and exit pipe connections *B* and *C*. A hollow sectional cylinder indicated at *D*, is mounted on a shaft *E* to revolve eccentrically with reference to the casing *A*, and in running contact with the casing at *F*. Two plate-like impellers mounted in suitable slots in the casing *G* and *H*, slide in and out of the slots during the revolution of the drum and transfer the air from the inlet

B to the outlet *A*. This type of blower is used only in small sizes and is not used extensively for cupola blowing.

Construction and operation of the Roots blower is clearly in-

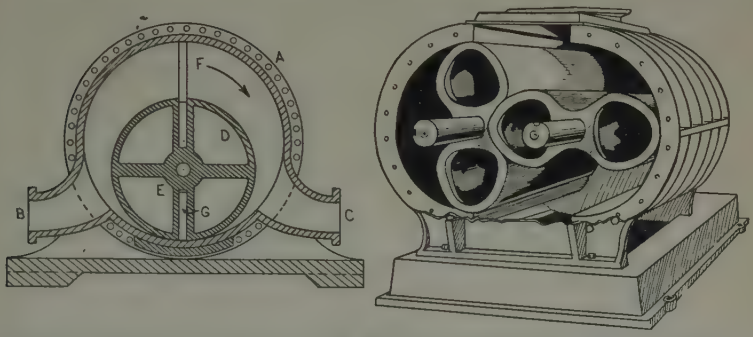


FIG. 101—(LEFT)—SIMPLE POSITIVE PRESSURE BLOWER. FIG. 102—(RIGHT)—INTERIOR VIEW OF ROOTS TYPE ROTARY BLOWER SHOWING TANGENT AIR IMPELLERS AND THE SIMPLE, RUGGED CONSTRUCTION

dicated in the interior view of this machine, Fig. 102. Two impellers mounted on parallel shafts rotate in opposite directions. Relation of impellers to each other is maintained accurately throughout the revolution by timing gears, one on the end of each shaft. Shape of these impellers insures a definite, accurately gaged clearance at the contact line at all times. They revolve without internal friction, and no internal lubrication is required between the impellers.

When an impeller is in the position in which one tip has just cut off the opening to the suction side, and the opposite tip is ready to open to the discharge side, a volume of air is trapped between the impeller and the case, which is not open to either the suction or the discharge. As the impeller continues to rotate it opens to the discharge and pushes the enclosed volume of air positively into the discharge system. The action is repeated twice for each revolution of an impeller or four times for each revolution of the blower.

Clearance between the tips of the impellers and the casing of the blower is slight. They are made practically air tight by a mixture of tallow and plumbago in the proportion of 3 to 1. Actual contact does not exist between the impeller tips and therefore the slip is reduced to a minimum.

Needless to say, great care is required in the accurate machining, fitting, balancing and tuning of the parts. Good and thorough workmanship is called for in the construction of these machines. Blowers can be operated by any convenient form of power. Belt drive from a motor, engine or lineshaft is the most

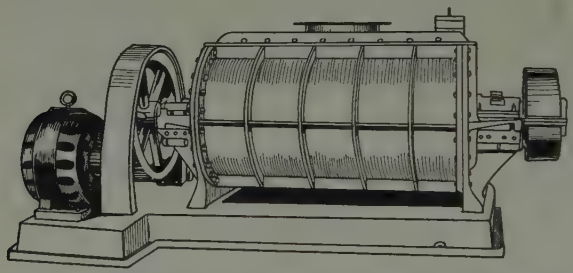


FIG. 103—COMPLETE BLOWER AND MOTOR ASSEMBLY

popular although the tendency now is to adopt direct electric motor drive. The motor is mounted on an extended bed plate and direct connected to the driven shaft by a gear and pinion. A complete motor-driven assembly is illustrated in Fig. 103. Where

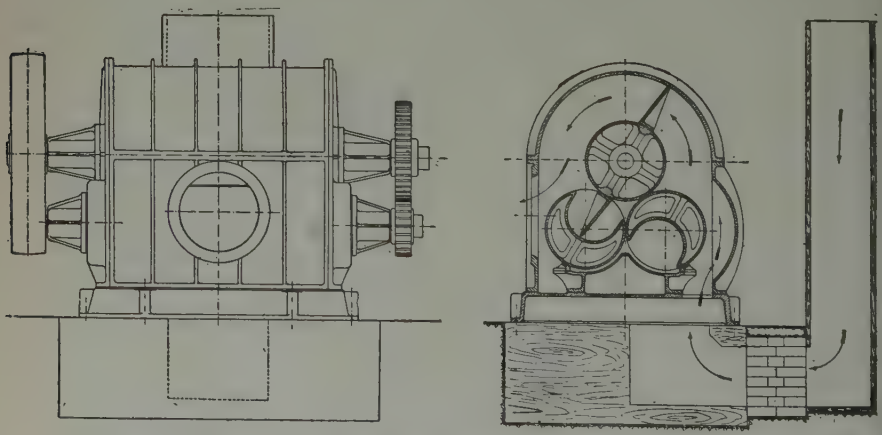


FIG. 104—SIDE AND SECTIONAL VIEW OF BAKER TYPE POSITIVE PRESSURE BLOWER FOR CUPOLA

a belt drive is used, the pulley on the driven shaft preferably is supported by an outboard bearing.

Blowers generally are arranged for top discharge with a

weighted relief valve mounted on the discharge pipe plate and with an opening on the suction side the entire length of the impellers. The blower can be arranged for bottom discharge with

Table XVIII

CAPACITIES AND OUTPUTS OF STANDARD ROOTS BLOWERS

No.	Cupola Size: Inside Diameter	Cupola Size: Capacity Tons per Hour	Blower Speed R.P.M.	Net Capacity Cubic Feet per Minute	Brake Horsepower: 8 oz.	Brake Horsepower: 12 oz.	Brake Horsepower: 16 oz.	Size Outlet Inches
	21	1	220	500	1.5	2.3	3.1	
1	23	1¼	260	625	1.9	2.8	3.8	8
	24	1½	300	750	2.1	3.2	4.2	
	27	2	390	1000	2.7	4.1	5.5	
	24	1½	200	750	2.3	3.4	4.6	
2	27	2	255	1000	2.9	4.3	5.2	10
	30	3½	410	1750	4.7	7.0	9.3	
	28	2½	185	1250	3.7	5.5	7.3	
3	30	3½	245	1750	4.6	6.9	9.2	12
	32	5	335	2500	6.6	9.9	13.2	
	33	5	220	2500	6.9	10.3	13.7	
4	37	6	260	3000	8.0	12.1	16.1	14
	42	7	295	3500	9.2	13.7	18.3	
	42	7	205	3500	9.5	14.3	19.0	
5	45	8	230	4000	10.7	16.1	21.4	16
	48	10	280	5000	13.0	19.5	26.0	
	48	10	195	5000	13.0	19.5	26.0	
5½	54	12	230	6000	15.4	23.1	30.8	18
	58	13	250	6500	16.7	25.1	33.4	
	54	12	170	6000	15.5	23.3	31.0	
6	60	14	195	7000	18.3	27.4	36.6	20
	64	16	220	8000	20.1	30.2	40.2	
	62	15	155	7500	18.8	28.2	37.6	
6½	66	18	185	9000	22.5	33.7	44.9	22
	72	21	215	10500	26.1	39.2	52.2	
	66	18	155	9000	22.7	34.1	45.4	
7	72	21	180	10500	26.3	39.4	52.6	24
	78	24	205	12000	30.0	45.0	60.0	
	72	21	140	10500	26.9	40.3	53.7	
7½	78	24	155	12000	29.8	44.6	59.5	28
	84	28	180	14000	34.5	51.9	69.1	
	84	28	135	14000	35.7	53.5	71.3	
8	87	30	140	15000	37.0	55.5	74.0	30
	90	33	155	16500	40.9	61.4	81.8	
	2-66	36	170	18000	44.8	67.4	89.7	

Table XIX

CAPACITIES AND OUTPUTS OF BAKER BLOWERS

No.	Displacement in cubic feet per revolution	R.P.M.	Weight of iron melted per hour tons	Internal Diam. for which blower is suitable---inches	Cubic feet passed per hour	Diameter of outlet inches
¼	0.75	250	.....	.....	11,250	3.75
½	1.5	250	0.5	14-18	22,500	3.75
1	3	240	1	18-22	43,200	6
2	6	200	2	22-27	72,000	9
3	9	175	2½	27-30	94,500	9.5
4	13	165	3	30-34	128,700	11.5
4½	17	150	5	34-40	153,000	11.5
5	25	140	8	40-48	210,000	15
5½	30	130	10	48-52	334,000	16.5
6	45	130	14	50-62	451,000	20.75
7	60	130	20	62-72	468,000	24
7½	72	130	22	62-72	561,600	24
8	100	130	28	72-90	780,000	28

the relief valve in the pipe line. Rated capacities of Roots' foundry cupola blowers are given in Table XVIII, also brake horsepower at pressures of 8, 12 and 16 ounces. Under favorable conditions, efficiency of these blowers is as high as 85 per cent and under general foundry conditions, 66 to 70 per cent. Power required can be ascertained from the relation:

$$BHP = \frac{V \times P}{33{,}000}$$

Where V = Volume of air in cubic feet per minute,
P = Pressure in pounds per square foot.

Values obtained from this relation multiplied by 1.5 will give a sufficiently close approximation to the actual power required.

In the Baker blower, illustrated in Fig. 104, the impellers attached to the upper rotating drum sweep out the volume of air included in the hollows of the two crescent shaped drums during the rotation. For the same air delivery, this machine runs at a lower speed than the Roots blower, but the power consumption is approximately the same. Rated capacities of standard sizes are given in Table XIX.

Rotary blowers should be mounted on rigid foundations and great care paid to their leveling and alignment in all directions. Taper bearings or taper wedges allow adjustment for journal wear. Adjustment should be made while the machine is running. The sound of the blower at once indicates the character of adjustment. The blower either should be housed in a place free from foundry dust, or, other precautions taken to prevent the entry of dust into the mechanism.

Delivery of air at pressures of from 1 to 2 pounds per square inch constitutes heavy duty for single stage fans, and for this reason centrifugal fans are designed carefully with a large number of vanes and a carefully shaped casing or scroll. Typical example of a single stage fan made by the General Electric Co. coupled to an alternating current motor for cupola blowing purposes, is illustrated in Fig. 107. All fans run at high speeds, and for that reason sudden jerks in stopping and starting are un-

desirable. They may upset the balance of the motor by distortion of the weaker parts under the shock. A direct driven fan is desirable for this reason. At high pressures, fans consume more power than blowers for the same quantity of air moved.

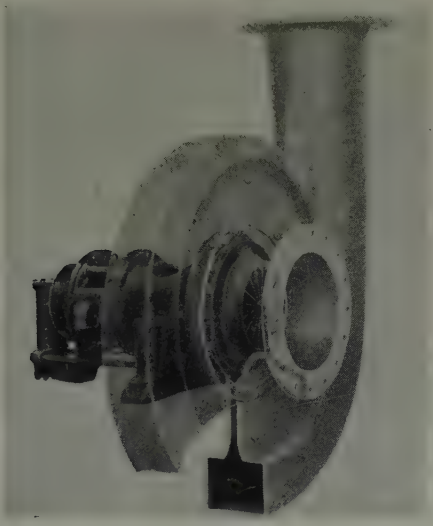


FIG. 105—PHANTOM VIEW OF A SINGLE STAGE SINGLE INLET CENTRIFUGAL FAN

In the centrifugal fan, the air drawn in at the center of the eye of the motor, illustrated in Fig. 105 is entrained by the specially shaped entrance buckets of the rotor, mounted on and rotated by the extended motor shaft. The entrained air is led through specially shaped impeller passages from which it is discharged into the stationary scroll shaped casing specially designed to slow down the velocity acquired by the air leaving the tips of the impeller and converting the velocity energy into pressure energy. Standard ratings of fans of this design are included in Table XXI from 0.75 pound to 2.0 pounds per square inch pressure. Characteristic curves in Fig. 106 indicate actual performance of these fans over a wide range of deliveries. Table XVIII is of additional interest in giving the rated outputs of another fan related to the diameter and output of the cupola.

Fans usually are driven by alternating current motors, but

where control over the delivered volume is needed direct current and a variable speed motor are required. Usually with an increase in speed and power an increase of 33 1/3 per cent over the rated delivery capacities of the fans may be obtained.

Since the best results in the melting operation depend on

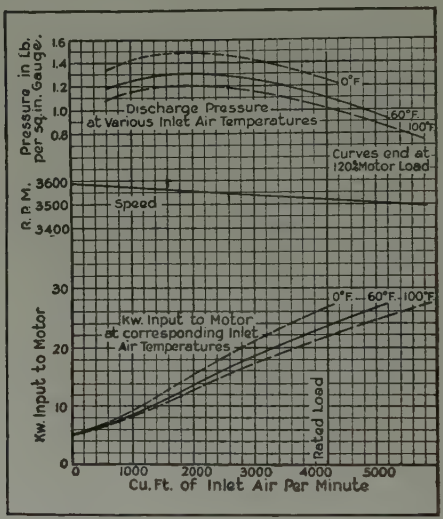


FIG. 106—CHARACTERISTIC CURVES OF COMPRESSOR RATED AT 4200 CUBIC FEET PER MINUTE

having the weight of air, iron and coke under complete control, the next step is to introduce an apparatus and a method of controlling the weight of air supplied to the cupola. Obviously, the resistance of flow of air through a cupola varies from minute to minute with the constantly changing conditions.

An electrical control device recently developed by the General Electric Co. is connected with the line supplying current to an electric motor operating a centrifugal compressor with characteristics suitable for this purpose. This control operates an artificial restriction, placed in the pipe between the blower and the cupola. This compensates for changes in cupola restriction, as well as for changes in atmospheric conditions, so as to maintain a constant weight of air flowing at all times. The mathe-

matical theory of the operation of this apparatus also extended reference to other details, appeared in *The Foundry* Feb. 15, 1929.

The control system operates on the principle that a blower and motor of suitable type have such characteristics that con-

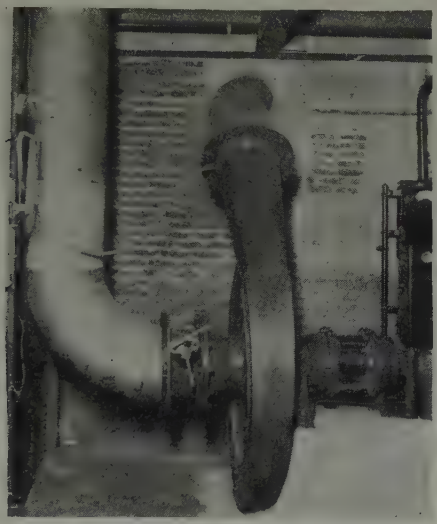


FIG. 107—SINGLE STAGE CUPOLA FAN, DRIVEN BY 27-HORSEPOWER MOTOR AT 3600 REVOLUTIONS PER MINUTE

stant weight of air is delivered when the electrical input in kilowatts is maintained constant. The apparatus consists of a blast gate which supplies an artificial restriction in the line and is manipulated to give the motor input the desired constant value. This manipulation may be done by hand with an ordinary watt meter, and hand blast gate, or it may be done automatically and thereby eliminate the personal equation.

The distribution main leading from the blower to the cupola should be as straight as possible. All sharp bends should be avoided and where other bends are necesary, they should take an easy curve. The pipe should have a larger diameter than the blower outlet. Usual recommendation for a short length is 25

per cent and for a long length 50 per cent larger. Table XXIII indicates necessary increase in blast pipe diameter with increased length.

In cupola economy, quantity, weight or volume of air delivery is just as important as the quantity of fuel, the other

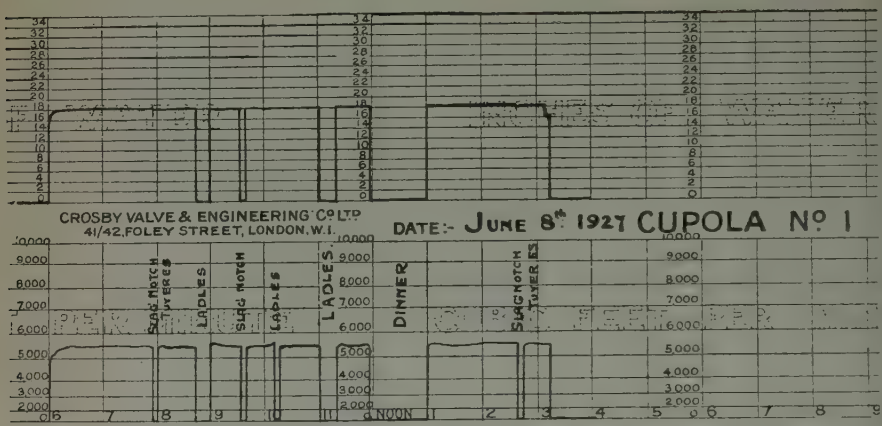
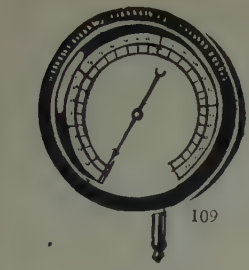


FIG. 108—BLAST RECORDER CHART FROM AN AVERAGE DAY'S HEAT TYPICAL OF GOOD PRACTICE

participant in the combustion reaction which provides necessary heat for melting the iron. Consequently, measurement of air becomes a factor of considerable importance in the scientific control of the cupola. Where a positive pressure blower is in use the quantity of air can be determined from the number of blower revolutions. A simple pressure gage or a relief valve set to open at a definite pressure at once indicates undue resistance to the passage of the air. With fan blowers the quantity of flowing air can be determined only with reasonable accuracy by some form of measuring instrument.

Measurement of direct or static pressure of the blast is comparatively simple. No elaborate instruments are necessary. The simplest form of instrument for this purpose, the liquid manometer, is a glass U-tube containing a suitable liquid, water, carbon tetra-chloride or mercury. Both members of the tube are marked with a graduated scale to show inches of water or ounces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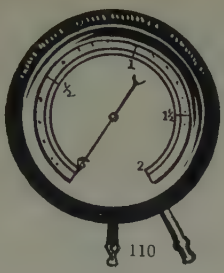
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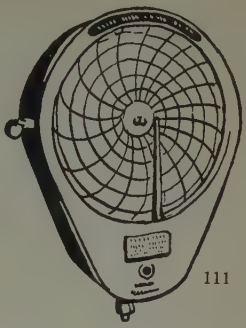
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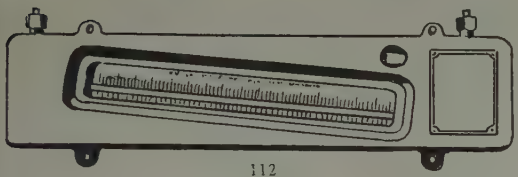
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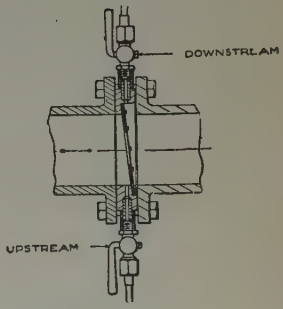

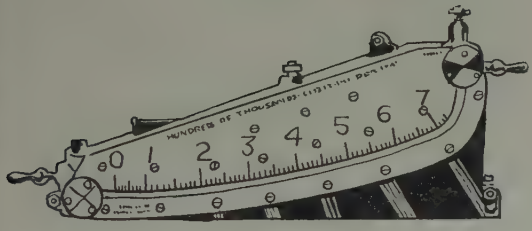
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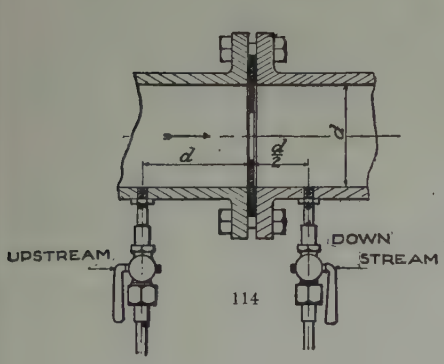

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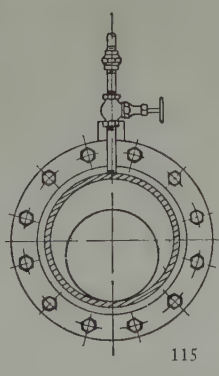
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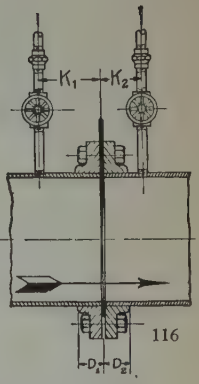

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FIGS. 109, 110, 111—DIRECT READING, DIFFERENTIAL AND RECORDING PRESSURE GAGES. FIGS. 112 AND 113—INCLINED TUBE AND CURVED TUBE MANOMETERS. FIGS. 114, 115 AND 116—VARIOUS TYPES OF ORIFICE PLATES

or pounds per square inch. One end of the manometer tube is connected to the air supply, and the other remains open to the atmosphere. Difference in level of the liquid in the two limbs of the manometer is produced by blast pressure. For purpose of comparison the factors shown in Table XXI will be found useful.

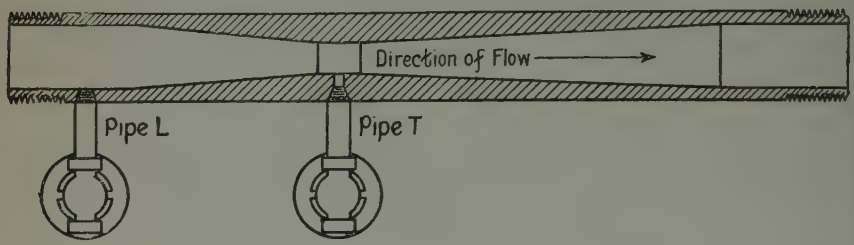


FIG. 117—SECTIONAL VIEW OF VENTURI TUBE

Direct reading pressure gages of the Aneroid and Bourdon type also are used and these principles are embodied in the production of recording pressure gages. These need considerably less attention in use but they are more expensive. Figs. 109, 110, and 111 respectively are typical of the direct reading and recording dial type pressure gages. The direct reading gage contains no liquid. The back portion of the metal case forms a chamber closed by a spring controlled diaphragm. A short tube from this chamber is connected by a length of tubing to a small diameter pipe leading to the position where the pressure is to be measured and the front is open to atmospheric pressure. The diaphragm is connected by a rack and pinion movement to a pointer which moves over a gradual dial.

Table XX

CONVERSION TABLE FOR OUNCES AND INCHES

One inch of water	=	0.58 ounces (approximately) per square inch
One inch of water	=	0.03625 pounds (aproximately) per square inch
One pound per square inch	=	27.6 inches of water
One inch mercury	=	8.00 ounces (approximately) per square inch
One inch mercury	=	0.5 pound (approximately) per square inch
One pound per square inch	=	2.00 inches mercury
One inch carbon tetrachloride	=	0.94 ounces per square inch
One inch carbon tetrachloride	=	0.5875 pounds per square inch
One pound per square inch	=	17.00 inches carbon tetrachloride
One ounce per square inch	=	1.62 inches carbon tetrachloride

Recording dial type instruments utilize the familiar Bourdon tube connected to a union by which it can be attached to a copper tube leading from the position in which the pressure is to be measured. Movements of the Bourdon tube are communicated to a pin arm moving over a flat circular chart, rotated by

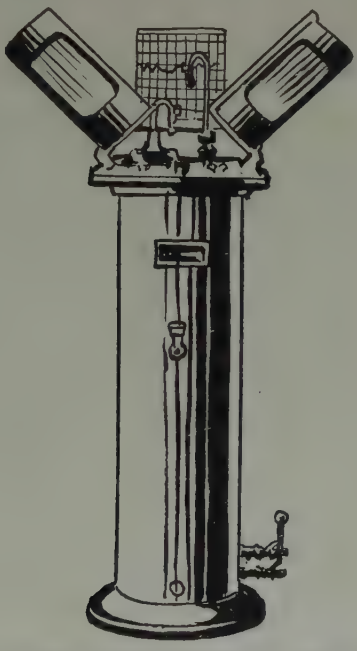


FIG. 118—BLAST RECORDER FOR INDICATING PRESSURE AND VOLUME

clockwork. The chart performs one revolution in 24 hours or in 7 days as desired. A pen lifting device automatically holds the pen clear of the chart when the case is opened. The charts, of course, are constructed with circular co-ordinates.

Flowing air conditions and influence of various factors on these conditions are understood sufficiently to warrant construction of measuring instruments sufficiently reliable for industrial purposes. Experiment has shown that the flow of gaseous fluids as a whole presents a problem of considerable complexity. One that is influenced by numerous conditions including nature of

the fluid, and the shape and character of the channels in which the fluid is flowing. Conditions under which measurement of the quantity of flow is desired, must be carefully defined. Various methods of measurement adopted are not universally applicable over all conditions and ranges of flow.

Quite a large number of different principles are utilized in

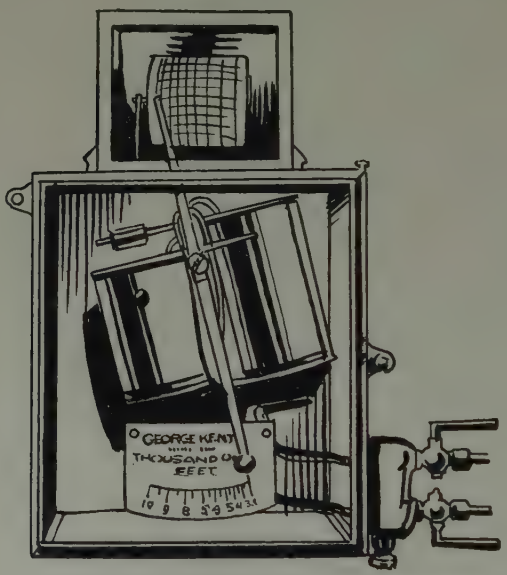
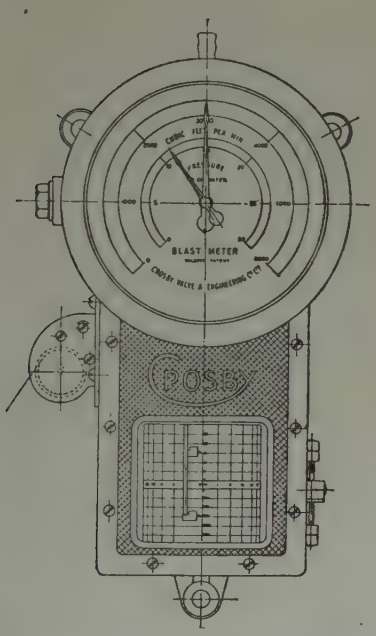


FIG. 119—BALANCED MANOMETER RECORDER

the design of many types of available air volume meters, but only a few have been adopted in measurement of cupola air supply. The three main principles adopted in cupola air meters follow: (1) Measurement of velocity at a point in the cross section of the stream. This method is embodied in the various pitot tube meters. (2) Measurement of drop in pressure due to an obstruction placed in the air stream, a method exemplified in the various venturi and orific meters. (3) A weight controlled paddle placed in the air stream, illustrated in the Wilson-Crosby volume meter.

Meters based on any of these three systems vary consider-

ably in the methods in which results are rendered visible or transferred to the recording mechanism. It is neither necessary nor possible to describe every type of meter in a work of this kind. Description of the principles embodied in each of the three types of meters, with typical illustrations of industrial instruments will be sufficient.



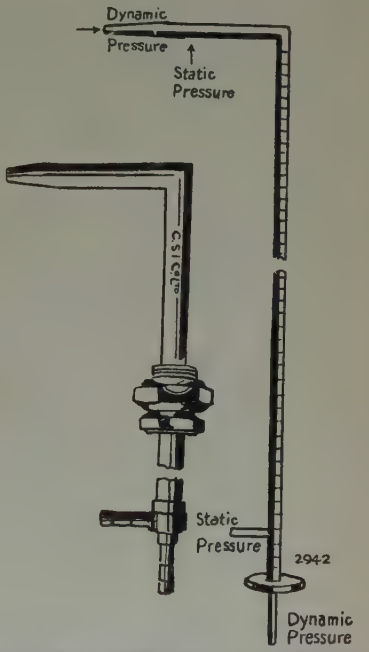


FIG. 120—(LEFT)—THE WILSON-CROSBY BLAST RECORDING INSTRUMENT.
FIG. 121—(RIGHT)—PITOT TUBES INDICATE STATIC AND DYNAMIC PRESSURES

Measurement of velocity at a point in the cross section of the air supply is carried out conveniently by a pitot tube. This device is convenient for industrial use, where it is inserted in a hole drilled and tapped in the blast pine. Connections to the gage are made by flexible tubing. Under laboratory conditions, measurements can be obtained to a high degree of accuracy. A pitot tube consists of two parts, a dynamic tube pointing upstream, parallel to the current of air, which determines the sum

of the velocity and static pressures, and a static tube by which the static pressure alone is determined. The patterns illustrated are the result of experiments at the National physical laboratory.

Two brass tubes are arranged concentrically. The inner, or

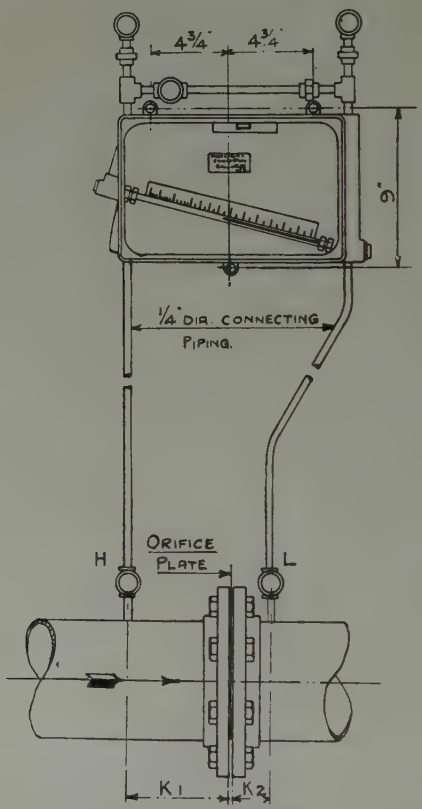


FIG. 122—DIAGRAM SHOWING ARRANGEMENT OF ORIFICE PLATE AND MANOMETER

dynamic tube, has a thin-lipped orifice protected by a plug when not in use. The outer, or static tube has a conical stopped end with small holes drilled perpendicular to the axis below the cone. Difference in pressure between the two tubes, is proportional to the square of the velocity of the flow of gas. Fig. 122, left, shows a pitot tube for industrial use, fitted with a screwed gland by

which it may be fixed in the pipe and adjusted for pipes of different diameters. Sometimes the screwed gland functions as a universal joint. Fig. 122, right, shows the standard laboratory pattern suitable for immersion up to about 13 inches (33 centimeters).

Difference in pressure between the two tubes may be measured in the simplest manner by a liquid manometer U tube in which one leg of the manometer is connected to the inner and one to the outer tube. Under normal conditions this difference is slight. Accuracy in reading the pressure differences is increased by special manometer tubes, typified by the inclined and the curved types indicated in Figs. 113 and 115.

Table XXI

CENTRIFUGAL COMPRESSION RATINGS

Cubic Feet Free Air Per Minute	H. P. of Motor	Approximate Ship. Wt. in Lb. A-c	Approximate Ship. Wt. in Lb. D-c	Cubic Feet Free Air Per Minute	H. P. of Motor	Approximate Ship. Wt. in Lb. A-c	Approximate Ship. Wt. in Lb. D-c
0.75 Lb. Pressure per Sq. In.—3500 R.P.M.				1.25 Lb. Pressure per Sq. In.—3500 R.P.M.			
600	3	1120	1400	900	8	1340	1540
1100	5	1310	1600	1500	12	1635	1835
1600	8	1750	1945	2300	18	2045	2625
2100	10	1935	.....	3500	27	2250	2755
2400	12	.....	2135	5300	40	3410	3700
4000	18	2340	2885	7500	58	4115	4900
5300	27	2745	3135	10500	85	5460	6185
7300	40	3835	4410	16000	120	6675	.....
10600	58	5660	6585	21000	170	9100	.....
14200	85	7175	8350	.....	.....	.....	.....
1.0 Lb. Pressure per Sq. In.—3500 R.P.M.				1.5 Lb. Pressure per Sq. In.—3500 R.P.M.			
600	5	1185	1400	1200	12	1440	1625
1200	8	1535	1745	1800	18	1815	2400
1600	10	1855	.....	2800	27	2685	3090
1700	12	.....	2040	3800	40	3750	4185
2800	18	2135	2715	6200	58	4300	5425
4200	27	2420	2935	9500	85	5170	5910
6000	40	3715	4030	13000	120	6275	.....
8500	58	4535	5335	18000	170	.....	.....
13000	85	5940	6660	.....	.....	.....	.....
17000	120	8150	.....	.....	.....	.....	.....

An ingenious adaptation of the manometer to continuous records is illustrated in Fig. 120. Two liquid containing vessels connected underneath are balanced on a knife edge and one of the differential pressures to be dealt with is introduced into each vessel by a flexible tube. Difference in pressure so introduced causes the liquid to shift from one vessel to the other, thus altering the center of gravity of the apparatus and causing the pen and the pointer to move across the chart and scale respectively.

In another hydrostatic type of recorder illustrated in Fig. 119 the recording pen arm is controlled by the vertical movement of a float, which rises and falls with variations of pressure. The pen traces the records in rectangular co-ordinates upon the chart wound around a clock driven drum. A differential dial gage of the diaphragm type, exactly similar in appearance to that illustrated in Fig. 110 may be used. The diaphragm is not exposed to the atmosphere on the front side. It is connected to the second limb of the pilot tube and the movements of the diaphragm thus actuated by the differential pressure. Graduation of the scales is effected by calibration of the instrument under standard conditions, and usually read directly in cubic feet per minute.

To insure accuracy the pitot tube should be installed in a straight length of pipe free from eddy currents set up by bends and corners. Preferably the length of straight pipe in which the tube is installed should not be less than 6 feet. The tube is inserted a distance equal to approximately 1/3 the diameter of the pipe.

The venturi tube shown in Fig. 118 consists of a pipe tapered internally from both ends to form a small orifice near the center. This obstruction to the passage of air causes a drop in pressure at this point from the normal pressure existing in the main. The drop in pressure is caused by the increase in velocity and a measurement of the pressure difference between that of the main stream and that at the throat of the venturi tube determines the velocity or quantity of air passing.

Pressure differences are measured by instruments similar to those already described in connection with the pitot tube. The pressure differences in the venturi tube may exceed those in the pitot tube. Therefore, more robust measuring instruments may be employed to obtain greater accuracy of measurement. Proportions of the tube are determined by the measuring apparatus used. Tubes of correct proportions are supplied by makers of the instruments. Meters are calibrated to read in cubic feet per minute.

Table XXII

DIAMETERS OF PIPES FOR VARIOUS LENGTHS OF AIR MAINS

Length of Pipe / Diameter of Blower Outlet	30 Ft.	60 Ft.	90 Ft.	150 Ft.	180 Ft.	240 Ft.	300 Ft.
			Diameter of Pipe Should Be				
3	3¼	3⅝	4	4½	4¾	5⅛	5½
3½	3¾	4⅛	4½	5	5¼	5⅝	6⅛
4	4⅜	4¾	5⅛	5¾	6	6½	7
4½	5	5⅜	5¾	6⅜	6¾	7¼	7⅞
5	5½	6	6⅜	7⅛	7½	8⅛	8¾
6	6½	7	7⅝	8½	9	9¾	10½
7	7⅝	8¼	8⅞	10	10⅜	11⅞	12⅛
8	8¾	9½	10⅛	11⅜	11⅞	12⅞	13⅞
9	10	10¾	11½	12¾	13⅜	14½	15⅝
10	11	11⅞	12¾	14¼	14⅞	16⅛	17⅜
11	12	13	13⅞	15⅝	16⅜	17¾	19⅛
12	13⅛	14¼	15¼	17	17⅞	19⅜	20⅞
13	14¼	15⅜	16½	18⅜	19¼	21	22⅝
14	15⅜	16⅝	17¾	19¾	20¾	22⅝	24¼
15	16½	17¾	19	21¼	22¼	24¼	26
16	17½	19	20⅜	22⅝	23¾	25⅞	27¾
17	17⅝	20⅛	21½	24	25¼	27½	29½
18	19¾	21⅜	22¾	25½	26¾	29⅛	31¼
19	20⅞	22½	24	27	28¼	30¾	33
20	22	23⅝	25⅜	28⅜	29¾	32¼	34¾
21	23	24⅞	26⅝	29¾	31⅛	33⅞	36⅜
22	24⅛	26⅛	27⅞	31⅛	32⅝	35½	38⅛
23	25¼	27¼	29⅛	32½	34⅛	37⅛	39⅞
24	26½	28½	30⅜	34	35⅝	38¾	41⅝

In principle the orifice plates shown in Figs. 114, 116 and 117 are similar to that of the venturi tube. Pressure difference created by the insertion of a plate obstruction containing an orifice of smaller diameter than the bore of the pipe is measured. Throttling the air flow in this manner creates a pressure difference proportional to the volume of air flow as follows:

$$V = K \times F \sqrt{\frac{h}{Y}}$$

Where V = Volume of cubic feet per hour
K = a coefficient
F = area of orifice in square inches
Y = specific gravity
h = pressure difference in inches of water

Typical examples of many types and arrangements of orifice plates are indicated in Fig. 114, 115, and 116. Plates generally are made of monel metal, and may be inserted readily between flange joints of the pipe line. The distances K_1 and K_2, Fig. 116, must be determined for any given installation. This information is supplied by the instrument makers. Differential pressure as with other devices is measured by various types of manometer tubes or recording instruments as illustrated in Fig. 122.

The Wilson-Crosby blast meter shown in Fig. 120 operates on a different principle to those already described. A balanced disk in the pipe line is mounted on a rocking lever. The movement of this disk, proportional to the velocity of air flow, is transmitted by a cord to the recording instrument. This recording instrument combines a direct reading and recording instrument

Table XXIII

TABLE OF OUTPUTS OF CUPOLA FANS

Diam. of Fan W. G. ins.	20-inch			25-inch			30-inch			35-inch		
	Volume	R.P.M.	B.H.P.	Volume	R.P.M.	B.H.P.	Volume	R.P.M.	B.H.P.	Volume	R.P.M.	B.H.P.
6	700	1400	1¼	1270	1110	2¼	1980	925	3½	2830	800	5
8	820	1600	2	1470	1280	3½	2280	1070	5¼	3260	920	7½
10	910	1800	2¾	1640	1430	4¾	2550	1200	7½	3650	1020	10¾
12	1000	1970	3½	1800	1570	6¼	2800	1310	9¾	4000	1120	14
14	1080	2130	4½	1940	1700	8	3020	1410	12½	4300	1210	17½
16	1160	2280	5½	2080	1810	9¾	3230	1510	15	4600	1300	21½
18	1230	2420	6½	2200	1920	11½	3430	1600	18	4900	1370	26
20	1300	2550	7½	2320	2030	13½	3620	1690	21	5160	1450	30
22	1360	2670	8¾	2440	2120	15¾	3800	1780	24½	5400	1520	35
24	1420	2780	10	2540	2220	18	3960	1850	27½	5650	1590	39½
26	1470	2900	11¼	2650	2310	20	4120	1930	31½	5900	1650	45
28	1530	3000	12½	2750	2400	22½	4280	2000	35	6100	1710	50
30	1580	3120	14	2850	2480	25	4420	2070	38½	6340	1770	56

with a direct reading static pressure dial. The dials are graduated by calibration under standard conditions of air flow. Among the merits of this instrument are simplicity in operation and maintenance coupled with stout construction; highly desirable features in instruments employed around a cupola plant. Typical diagrams from one of these instruments are illustrated in Fig. 108.

CHAPTER X

Linings

Early linings—Stone linings—Fireclay bricks—Melting points—Spalling tendencies—Chemical inertness—Care of fire bricks—Cupola blocks and linings—Iron bricks—Patching and daubing—Monolithic linings—Silica—Bauxite—Sillimanite—Chromite—Kieselguhr—Carborundum—Other refractories.

ALL metallurgical operations involve the use of heat supplied in furnaces of various types designed to withstand high temperatures, and to conserve the heat from waste due to losses apart from the desired reactions. This material must be sufficiently inert to prevent the introduction of any undesirable constituent in the final product.

From earliest times plastic and more or less siliceous clays have been used for this purpose. Earliest shaft furnaces used for smelting were constructed almost entirely from plastic clays. These furnaces possessed in varying degree the desired properties of heat insulation and neutrality to the smelting reactions, insofar as they concerned the introduction of impurities into the final metal. With the development in size and dimensions of shaft furnaces, these plastic linings gradually were superseded by built up linings. In the early days of iron smelting, blast furnace and cupola linings were constructed almost entirely of dressed stonework. Use of stonework lining for foundry cupolas is within the memory of many foundrymen still living and several stone lined cupolas have been in use in Great Britain practically up to 1914.

Probably the square construction adopted in early cupolas was determined largely by this use of dressed stonework, involving as it did considerably less labor than cylindrical construction. According to Overman, the coarsest sandstones were best. Red sandstones and millstone grits underlying coal measures also were found to give good results. Gornal sandstones of Staffordshire were favored for this purpose in Great Britain.

Lining of the modern foundry cupola is constructed almost universally of fireclay bricks although there is a reversion to

the old type of lining, certain plastic clays, under the more ambitious modern title of monolithic linings. This feature will be considered at a later stage.

Fireclay bricks or firebricks are made from siliceous fireclays found in various districts scattered all over the world. Basis of all clays is the so-called kaolin or china clay, found mixed with water, hydrated iron oxides, quartz and organic matter, to form variously colored plastic clays. In its purest form kaolin,

Table XXIV

TYPICAL ANALYSES OF STOURBRIDGE FIRECLAYS

		No. 1	No. 2	No. 3	No. 4	No. 5
Silica	SiO_2	56.11	64.65	50.65	47.40	72.92
Titanic oxide	TiO_2	.....	.....	1.44	1.25	1.26
Alumina	Al_2O_3	26.28	23.67	28.97	33.18	17.22
Ferric oxide	Fe_2O_3	2.51	2.16	2.99	1.72	1.32
Magnesia	MgO	0.11	....	0.67	0.36	0.27
Lime	CaO	0.94	0.28	0.47	0.38	0.16
Alkalies	K_2O & Na_2O	1.25	0.82	1.68	1.20	0.79
Loss when calcined over 109 degrees Cent.		10.99	8.53	12.92	14.12	6.00

a white powder, usually amorphous, is practically pure hydrated aluminum silicate containing silica (SiO_2) 46.40 per cent, alumina (Al_2O_3) 39.7 per cent, combined water 13.90 per cent.

Ordinary fireclays vary considerably in composition and almost always contain silica in excess of that present in pure kaolin. Typical analyses of British fireclays from the Stourbridge district are given in Table XXIV. These analyses represent clay in the dried condition, and the item "Loss when calcined over 109 degrees Cent. (230 Fahr.)" represents the amount of combined water and organic matter in the original clay. In the three typical analyses of firebrick given in Table XXV, this item is conspicuous by its absence, and thus clearly demonstrates the principal reason of firing or burning the brick to expel the whole of the combined water and organic matter in the original clay. After the firing process, the brick presents a dense hard body, possessing considerable mechanical strength. Usually it is nearly white or pale buff in color, depending upon the amount of iron oxide present in the clay.

Refractory bricks employed in the construction of metal-

lurgical furnaces should possess the following properties:

(a) High melting point and softening point under load.
(b) High resistance to spalling or disintegration under sudden changes of temperature.
(c) Low thermal conductivity.
(d) High resistance to erosion and corrosion under the particular conditions of operation.

Table XXV

TYPICAL ANALYSES OF THREE SPECIAL FIREBRICKS

	No. 1	No. 2	No. 3
Silica	81.6	42.6	50.01
Titanic oxide	0.7	1.8	3.61
Alumina	15.0	52.7	40.11
Ferric oxide	1.8	2.5	3.37
Magnesia	0.2	0.2	0.61
Lime	0.3	0.1	0.69
Alkalies	0.8	0.4	1.92
Loss when calcined over 109 degrees Cent.	Nil	Nil	0.24
Refractory test	1670-1690°C	Over 1770°C	1710°C

(e) Minimum change in shape and volume under heat influence.

Simultaneous occurrence of the optimum of all these properties in any one refractory probably is unattainable. Fireclays possess these properties combined in the most useful proportions and for this reason are the most important refractory materials available.

Melting points of unused fireclay brick range from 1480 degrees to 1730 degrees Cent. (2696 to 3146 Fahr.). Melting points and also softening temperatures of various commercial refractory materials under a load of 2500 pounds per square inch are shown in an accompanying table.

Brick	Range of Melting Points Degrees Cent.	Range of Softening Temperatures Degrees Cent.
Fireclay	1480-1730	1340-1480
Silica	1710-1720	1620-1675
Magnesite	1542-1710	1425-1565
Bauxite	1480-1595	1345-1480

Melting points and softening points of fireclay bricks, rise with increasing percentages of clay and are reduced by increasing percentages of impurities, including iron oxide, lime and alkalies. Addition of 0.50 per cent iron oxide above that usually present,

lowers the softening temperature 55 to 78 degrees Cent. (131 to 172 Fahr.). About 0.10 per cent lime lowers this temperature 40 degrees Cent. (104 Fahr.). Fine grained firebricks melt and soften at higher temperatures than coarsely grained material. Reduction in softening temperatures under load as illustrated is a factor of great importance in furnace construction. Use of badly shaped bricks often results in local concentration of the load, with a resulting local reduction in the softening point. This ultimately influences premature disintegration of the whole furnace lining.

Liability of bricks to spall has received considerable attention during recent years. Tendency to spall or to disintegrate under temperature changes is a peculiar feature. In a brick of any given size, it is related to the mechanical strength, thermal conductivity, and coefficient of expansion. These properties in their turn are influenced by the composition, density and structure of the brick. The higher the degree of porosity, within limits, the greater the resistance to spalling. The limiting feature of course is reduction of mechanical strength with increase in porosity. It has been stated that fireclay bricks with grains of 3 millimeters (0.12-inch) diameter are 3 times as resistant to sudden temperature changes as bricks with grains below 0.8 millimeter (0.03-inch) diameter.

Composition of the material and thermal conditions during the firing operation exert the greatest influence on the spalling tendency of firebricks. Constitutional changes during the firing, determine the character of the constituents in the final brick. These in turn determine extent and character of volume changes which occur when the brick subsequently is heated in the furnace.

Principal constitutional changes take place during firing in the free silica or quartz content. Free silica has a comparatively high coefficient of expansion. Under the influence of heat it undergoes certain transformations from the original natural quartz state into two modifications separately known by the mineralogical terms crystoballite and tridymite. These changes in modification are accompanied by volume changes particularly responsible

for spalling tendency when changes occur in the subsequent reheating of the bricks. Transformations only are partially accomplished in the original burning of the fireclay. Their extent is determined by the duration and temperature of the burning process. In normal firebrick burning 75 to 80 per cent of the natural quartz is transformed to crystoballite and tridymite with an accompanying increase in volume of about 20 per cent. Percentage of free silica or quartz as distinct from the clay content in the fireclay, and the correctness of the firing, exert considerable influence on the spalling tendency. From a series of tests, Surecht and his collaborator have shown that the ultimate chemical composition of the best fireclay bricks show that the ratio

$$\frac{\%SiO_2}{\%Al_2O_3 + \%\ (Fe_2O_3 + CaO + MgO + K_2O + Na_2O)}$$

falls between 1.5 and 2.6.

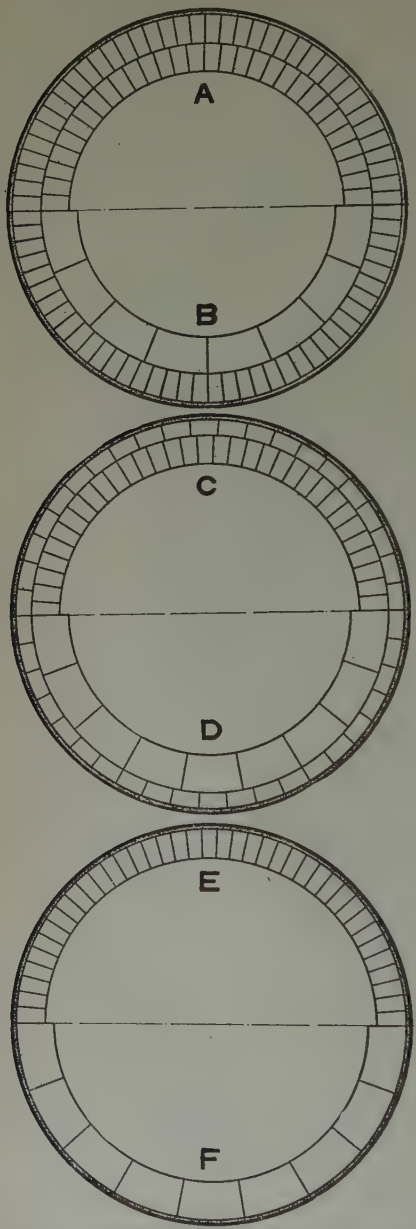
Spalling tendency in bricks at a low temperature of approximately 225 to 250 degrees Cent. (437 to 482 Fahr.) has been shown to be due to a sudden volume change of the crystoballite, which undergoes an inversion at this temperature. For this reason it is necessary to heat brickwork slowly beyond the temperature indicated and the repeated heating and cooling of brickwork past this temperature should be avoided wherever possible.

Magnesite bricks have the greatest spalling tendency of all refractory bricks. Comparative figures in an accompanying table show specific sensitiveness to spalling of common refractories, related to magnesite, at 100.

Specific spalling tendencies in common refractories.

Magnesite brick	100
Silica brick	75
Chromite brick	42
Zirconia	16
Bauxite	13
Fireclay	8-12
Carborundum	2

Pure clay is neutral. Fireclay departs from this neutrality according to its content of free silica. Chemical inertness toward basic influence is decreased accordingly. Furnace gases high in carbon monoxide content corrode brickwork, particularly if the bricks contain much oxide of iron (Fe_2O_3). This oxide is reduced to a lower oxide or to metallic iron by the carbon monoxide which



A—Double Lining

Arch brick 9 inch x 4½ inch x 2½ inch.

B—Double Lining

Arch brick and cupola blocks 9 inch x 6 inch x 4 inch.

C—Double Lining

Straight or split brick 9 inch x 4½ inch laid flat against shell. Arch brick 9 inch x 4½ inch or 4½ inch circle brick.

D—Double Lining

Straight or split brick 9 inch x 4½ inch laid flat against shell and cupola blocks.

E—Single Lining

Arch brick 9 inch x 4½ inch or 4½ inch circle brick is used (without a cushion) for the stack above charging door.

F—Single Lining

Cupola blocks 9 inch x 6 inch x 4 inch. A cushion is used with all linings.

FIG. 123—ALTERNATIVE METHODS OF BUILDING SINGLE AND DOUBLE LININGS IN THE CUPOLA

penetrates the pores of the brickwork. With reduction of oxide to iron, carbon is deposited in the pores of the brick and this ultimately is regasified with a consequent disruption of the material. Corrosion of bricks in this manner to an extent is determined by the porosity. Fortunately, comparatively rapid glazing of firebrick surface in cupolas prevents any extensive action from this cause.

New firebricks are weaker than used firebricks and should be handled carefully in transportation and in the foundry. Cupola blocks should be handled separately and every care taken to protect the edges and corners. Firebricks absorb water easily and absorbed moisture is particularly injurious, especially in cold weather. Cupola bricks should be kept in a dry place and stacked on dry floors. Firebrick never should be exposed to rain, frost or snow, and new bricks should be dried slowly and carefully to expel any absorbed moisture. Brickwork structures normally absorb a considerable amount of moisture from the jointing material. Hence the necessity for drying the structures carefully.

Firebricks of standard sizes generally are shipped loose. In general practice up to 10 per cent extra are shipped as spares to cover damage in transit. In the United States, bricks generally are shipped in box cars. Packing is advisable if not essential with special shapes, and crates generally are made up to about 700 pounds gross weight.

The standard 3 x 4½ x 9-inch brick, made in circle form commonly is used for cupola lining. The bricks are segmental, 4½-inch radial thickness, with a taper determined by the internal diameter of the desired circle. Various other shapes may be utilized according to individual taste. Bricks of larger sizes, commonly referred to as cupola blocks are preferred by many foundrymen for reduction in total number of joints in the brickwork as a whole. Typical shapes of bricks and methods of constructing linings from these shapes are illustrated in Fig. 123.

Brickwork joints generally are made with fireclay. To obtain best conditions, a fireclay is desirable having the same characteristics as that of which the bricks are made. Fireclay should be used sparingly. The thinner the joint the better. The aim should be a brick to brick joint. Firebrick makers prepare spe-

cial fireclays for jointing purposes. These jointing clays to which a proportion of burnt fireclay has been added change in volume less than green fireclay owing to a portion of their composition having undergone the change which takes place in burning. The fireclay should be prepared as a thin paste into which the bricks are dipped, and then rubbed into place to make a brick to brick joint. From 400 to 600 pounds of fireclay will lay 1000 bricks.

Several available cold setting cements are highly refractory and are marketed under special trade names. These materials set cold like cement to form a hard mass of considerable mechanical strength. These materials are more expensive than ordinary fireclay but additional costs are more than counterbalanced by saving, in amount of material used, and increased life of the brickwork lining.

In small cupolas a 4½-inch thick brick lining generally is sufficient. A 9-inch lining is recommended for larger cupolas. In all cupolas intended for use over prolonged daily periods or continuously, the minimum lining thickness should be 9 inches and even thicker linings are to be prefered. Usually a space of from ¼ to 1 inch is left between the brickwork and the cupola shell, and this space is filled with loose sand or fireclay. This space never should be left open. Danger exists of the accumulation in this cavity of explosive mixtures of carbon monoxide and air, as a result of the filtration of the gases through the brickwork. An explosion in this cavity possibly might wreck the whole cupola lining.

Steel angle rings, or cast iron segmental rings are bolted to the interior of the cupola shell at suitable levels for supporting the lining. These rings permit extensive mending and relining operations to be performed with safety in the event of damage to the lower portions of the lining.

In ordinary practice, openings around the fettling hole, slag hole and tap hole are made up with black sand or loam firmly rammed against the coke and held in position by the breast doors. Tap hole and slag hole are formed daily with a fireclay and sand or a ganister and fireclay mixture in some instances containing a small amount of coke, coal dust or foundry blacking.

In certain instances a firebrick tap hole is preferred and special large bricks are manufactured for the purpose containing the tap hole correctly located. Special tap hole blocks also are made from a material similar to that in plumbago crucibles, claimed to last from 3 to 6 months. Similar special runner bricks or spout liners also are available. It is claimed that slag and iron will not stick to this material as they do to ordinary fireclay brick, and it may be expected to last three or four years. It is of interest to note that under ordinary conditions, a ½-inch diameter tap hole will run 5 tons per hour; ⅝-inch diameter, 10 tons per hour and ¾-inch diameter, 15 tons per hour.

Maintainance cost of cupola firebrick linings can be reduced considerably by using cast iron bricks in the region around and below the charging door. At this point, particularly with certain forms of mechanical charging devices, repeated shocks, cause rapid disintegration of the brickwork. Cast iron bricks easily are made and may be set in position in a manner exactly similar to ordinary bricks. Diagrams of various forms are shown in Fig. 124. The form illustrated in the upper left is preferable to others. It is molded easily and it can be filled readily with loose firebrick and fireclay. The iron bricks are built completely around the inside of the cupola at and below the charging door level. The structure should be supported on a suitable cast iron or steel angle ring, bolted to the cupola shell. Usually the iron bricks are built down to a depth of 2 feet from the charging door level. A greater depth can be used with advantage and the author's own cupolas are lined to a depth of 4 feet.

Firebrick linings in foundry cupolas fail after continued operation as a result of slag erosion, chemical action with the slag forming materials and erosion and shock to which the lining is subjected by the heavy metal portions of the charge. Failure takes place at the brickwork joints made of fireclay. Life of the lining is prolonged by the use of large bricks or cupola blocks, which reduce the number of joints in the structure. Considerable erosion takes place each time the cupola is used. The brickwork is scored about the region of highest temperature or melting zone, and must be patched after each heat with ganister.

Ganister is a highly siliceous clay which resists satisfactorily the high temperatures involved, and also the chemical action of the slag and slag forming materials in the cupola. Unfortunately the bonding power of ganister alone is low, due to its high silica and low clay content. Ganister is improved by the addition of a small quantity of lime which under the influence of heat forms a glass like calcium silicate and helps to frit together and consolidate the ganister into a hard, solid, stony mass. This practice is followed in lining crucible furnaces. Rammed ganister or silica rock with 2 per cent lime addition has been recommended for long life cupola lining. Bonding power of ganister is improved considerably by milling, although it is claimed that excessive milling tends to reduce its refrac-

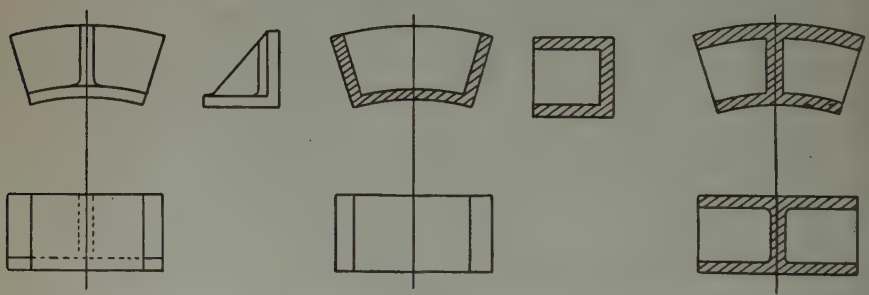


FIG. 124—VARIOUS SHAPED HOLLOW CAST IRON BLOCKS HAVE BEEN PLACED IN SERVICE IN THE CUPOLA LINING

toriness. Refractoriness of ganister is improved by the sizeable particles of practically pure silica which exist in the partially broken down material.

Although ganister is a natural product, it can be imitated satisfactorily by synthetic mixtures. As long ago as 1885, Bloxam states that a fairly good substitute for ganister can be made from powdered pure siliceous stone mixed with a certain amount of aluminous clay. Natural ganisters frequently are "improved" for cupola purposes by the admixture of an additional amount of clay. A typical mixture recommended for cupola purposes follows:

	Per cent
Ganister	40
Crushed old firebrick	40
Coke breeze	10
Fireclay	10

This mixture should be turned over in a pugmill for 10 minutes. It resembles the old time *brasque* mixtures in which coke dust or charcoal debris was added to better resist the action of corrosive slags. Another simple recommended mixture consists of equal parts of firebrick, fireclay and silica sand. These mixtures should be prepared fully 24 hours before they are used.

Natural ganister in England is a siliceous rock underlying the coal deposits of South West Yorkshire, North Derbyshire, South Lancashire and Cleveland district. The sedimentary rock is densely hard and contains silica up to 98 per cent. Ganister derives its refractory properties from this high silica content. For cupola purposes, ganister should not contain less than 92 per cent silica. Bonding power usually is improved by the admixture of fireclay which should not exceed 15 per cent.

Many other siliceous materials are used for patching, including a mixture of equal parts carborundum, fireclay and ground crucibles. Fire sand and fireclay in varying proportions are used extensively in American foundry cupolas. Use of materials in any given district ultimately is determined by their cost.

Extensive patching required in brick lined cupolas has received a great deal of attention. Common knowledge that weakness of the brick lining lies in fireclay joints has been referred to previously. Present tendency seems toward a reversion to monolithic lining. The tendency is due to some extent, particularly in this country, to discovery of various more or less siliceous clays which possess the necessary bonding power and necessary degree of refractoriness for the purpose.

Origin of monolithic linings dates back to remote antiquity. Modern use of these linings probably originated on the continent and certainly has been more common on the continent

than in this country. Some of the continental products have been exported for this same purpose.

In practice, the lining material generally is supplied in the milled condition practically ready for ramming into position. Suppliers usually advise that the material is improved by standing for a few days. The material should be as dry as possible, and still sufficiently plastic to be rammed. A wood plug or a metal liner ring corresponding in size to the internal diameter of the cupola is mounted centrally in position at the hearth level. The plastic material is introduced into the annular space between this plug and the cupola shell and rammed hard and solid into position. The plug is pulled upward a few inches at a time until the shell is lined completely. The lining material is rammed with flat rammers heated to prevent sticking.

Drying of this dense, hard rammed lining requires considerable care and attention. All moisture from the plastic mass must be expelled through the mass itself. To facilitate this passage, the solid lining should be vented carefully by a stout wire rod pushed completely through the radial thickness of the lining. The thicker the lining the more venting is required, and it may be considered as axiomatic, that venting cannot be overdone. Wisdom of using the plastic material in the dryest possible condition in which it can be rammed will be appreciated. This feature reduces the total amount of shrinkage of the lining on drying, a desirable feature in maintaining the strength and ultimately the life of such a lining. Following the venting process the lining should be dried carefully by a slow fire. After the lining is thoroughly dried, it is advisable to increase the intensity of the firing to the possible obtainable maximum.

Plastic materials used for monolithic linings consist essentially of silica and clay. Ultimate rigidity of the lining is determined by a well known characteristic of clay. At a sufficiently high temperature it becomes converted into a hard, more or less stony mass, as in bricks. The aim in making a monolithic lining should be to obtain a one piece lining with all the characteristics of brick.

In the usual rammed monolithic lining, complete burning

of the material is presumed to take place during the actual melting period. Effect of normal cupola operation in this direction presents a feature of considerable interest. Burning of clays in brick making takes place in two stages: The initial stage in which the included water is driven off, and the final stage in which the combined water is eliminated and the clay converted into the hard form. The final stage also is carried out at a sufficiently high temperature to obtain a complete fitting together of the various constituents to yield a brick of the desired hardness and mechanical strength. This temperature is determined principally by the character of the brick material and is higher in silica bricks than firebricks. The temperature in silica brick kilns is between cones Nos. 14 and 15, about 1450 degrees Cent. (2642 Fahr.).

Temperature conditions vary considerably in the thickness of cupola linings. A series of temperature determinations of

Table XXVI

CUPOLA TEMPERATURES

	Temperature Degrees Cent. I. D.	Temperature Degrees Cent. O. D.
Bottom zone	1550	143
Melting zone	1700	132
Middle zone	1300	130
Throat zone	850	75

the inside and outside furnaces of the cupola lining in different zones has been obtained by Piwowarsky and Broglio. These results are given in Table XXVI.

Correct burning temperature of monolithic lining plastic refractories which usually contain not less than 84 per cent silica is not as high as that required for silica bricks. For practical purposes it may be considered approximately 1000 degrees Cent. (1832 Fahr.). Correct burning temperature is defined as that used to obtain bricks of the necessary refractoriness and mechanical strength for cupola practice. Temperature on the outside of the lining and in the throat zone is not high enough to obtain proper burning conditions.

Temperature distribution burns the monolithic lining ma-

terial to brick hardness on the inside surface at the bottom, melting and middle zones. At the back of these zones and in the throat zone the material is improperly burnt and is mechanically weak. At the throat zone the temperature is hardly high enough to drive off the included moisture. Material at these points therefore must be mechanically weak. Obviously this is undesirable where the lining is subjected continually to shocks from charging heavy materials. Unfortunately the mechanical weakness is greatest in the throat zone where the lining sustains the maximum shock due to charging. For this reason monolithic linings in this zone are inferior to brick linings.

Various suggestions have been made, and some patented for improving the mechanical strength in the interior of monolithic linings. These suggestions generally involve the use of some type of reinforcement.

A row of ¼-inch diameter steel rods bent at right angles and spot welded to the furnace casing has been recommended for the monolithic linings of rotary heat treating furnaces. Various types of metallic reinforcement involving the use of steel bars or cast iron frames also have been suggested. The cupola referred to in the research by Piwowarsky and Broglio was lined with iron-armored silica paste. Interesting description of reinforcement applied to a dolomite lined cupola comes from Germany. The lining, a dolomite and tar mixture, is reinforced with steel turnings. The mixture is spread to a thickness of 3 to 8 millimeters (approximately ⅛ to ⅜-inch). A layer of steel turnings is applied, followed by successive layers of mixture and turnings, until the complete thickness is obtained.

Addition of comparatively large sized silica rock aggregate embedded in the plastic material, is common in England for reinforcing the lining as a whole. However, none of these methods will prevent the mechanical weakness of the lining in the throat zone in the neighborhood of the charging door. The only effective method for overcoming this difficulty is to use iron bricks from the charging door downward. Precaution should be taken to suitably support the iron bricks by a ring inside the cupola shell. An iron brick lining in the throat zone

properly and independently supported and a monolithic lining carefully prepared and preferably reinforced by comparatively large sized aggregate, constitutes a highly satisfactory cupola lining which will compare favorably with the usual brick lining.

Silica bricks are not used for cupola linings. They are acid in character and deteriorate rapidly under influence of limestone flux. Bauxite bricks are made from an aluminous clay varying somewhat in composition between the following limits:

	Per cent
SiO_2 and titanic acid	13-17
Al_2O_3	60-65
Fe_2O_3	4- 8
Comb. H_2O	15-17

Bauxite bricks do not possess any superiority over fireclay bricks to warrant their use in cupola linings.

Sillimanite variously known as cyanite (kyanite) or andalusite, an aluminum silicate composition $Al_2O_3 \cdot SiO_2$ containing about 37 per cent SiO_2 and 63 per cent Al_2O_3 has attracted considerable attention during recent years as a substitute for fireclay refractories. Some of the principal deposits of this material are found in India. The commercial material has an aluminum silicate content of 90 to 98 per cent, a melting point of about 1816 degrees Cent., (3360 degrees Fahr.) a low thermal expansion uniform up to high temperatures is neutral in chemical reaction and the coefficient of linear expansion from 20 degrees Cent. to 1000 degrees Cent. (68 to 1832 Fahr.) is 0.0000056.

Chromite bricks made from chrome ironstone are chemically neutral. Typical composition of this material follows:

	Per cent
Chromic oxide	42.0-60
Ferrous oxide	15.0-20
Alumina	15.0-16
Magnesia	15.0- 1.5
Lime	1.0- .5
Silica	7.0- 2.0
Water and organic matter	5.0- 2.0

Kiesel appears under various names including diatomite

and celite, and is a diatomaceous earth resulting from the decomposition of tiny micro-organisms, diatoms, which once existed in the ocean bed. It is highly siliceous in character, light in weight, composed of numerous tiny cells and has a high refractory and insulating power. The material is made up into bricks and finds extensive use where heat insulation is required. Kiesel has a thermal insulating power about equal to that of cork and a melting point of 1610 degrees Cent. (2930 Fahr.)

CHAPTER XI

Briquets

Losses in remelting—Calculation of mixtures—Separation of charges—Briqueting cast iron borings and turnings—Use of canister containers—Chemical binders—Bonding by rusting—Power pressing —Grading of borings and turnings—Remelting briqueted borings.

CERTAIN changes in chemical composition are brought about in remelting cast iron under normal cupola conditions. Early iron founders were familiar with an increase in hardness and closing of the grain. Prof. Thomas Turner explained these phenomena were due to the changes taking place during remelting, principally decrease in silicon content and increase in sulphur content. In 1853 Sir William Fairbairn carried out a series of experiments in which cast iron was remelted eighteen times in an air furnace. Changes in composition of material as disclosed by Prof. Turner's analyses are plotted in the diagram Fig. 125, and clearly show the steady decrease in silicon and manganese and the steady increase in sulphur and phosphorus with the successive remeltings.

Exactly similar changes accompany remelting of cast iron in the cupola. Under normal conditions it is common practice to allow for certain changes in a single remelting. These changes are expressed as a percentage of the original amount of the element present as follows:

Silicon 10 per cent loss
Manganese 15 to 25 per cent loss
Sulphur 35 to 50 per cent gain

A slight gain in phosphorus content frequently is experienced. Generally the amount does not total more than 0.10 per cent.

Invariably a certain loss occurs in the total iron content in the form of oxide of iron transferred to the slag. Total losses expressed as a percentage of the total melt of these constituents which occur by way of oxidation and slag reactions generally run from 0.8 to 1.7 per cent and of course these losses are inherent in ordinary cupola practice.

In many places today it is common practice to remelt irons containing certain proportions of nickel and chromium. Losses experienced in these elements vary considerably according to individual practice. Chromium to the extent of 50 per cent of the amount in the original charge frequently is lost in remelting. Changes up to 30 per cent frequently are experienced in the

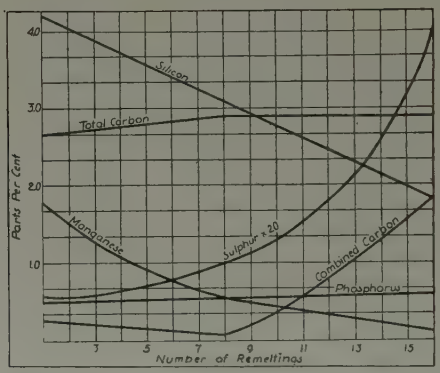


FIG. 125—CHANGES IN COMPOSITION DUE TO REMELTING CAST IRON

nickel content. The following example, taken from the writer's own experience, illustrates these losses:

	Calculated Composition Per Cent	Actual Composition Per Cent
Chromium	0.96	0.336
Nickel	4.00	3.46

Gross total losses in foundry cupola melting practice are made up of the foregoing items, losses of a mechanical nature inclusion of pellets of iron which remain suspended in the more or less viscous slag, metal unavoidably lost in splashes from the tap hole and slag holes, and metal lost when the bottom doors are dropped.

The American Foundrymen's association in 1901 made an exhaustive inquiry into the melting losses experienced in various gray iron foundries. Total losses as a percentage of the iron melted are tabulated under separate headings with complete data of the charges according to the classes of work upon which the

cupolas were engaged. The lowest total loss recorded was 1.7 per cent and the highest 11 per cent. With efficient practice the percentage loss is greater in small tonnage melts than in the melts of large tonnages. In common practice for costing purposes an average figure of from 5 to 7 per cent is used in cal-

Table XXVII

MATERIALS FOR CUPOLA CHARGE

	Pig Iron *A*	Pig Iron *B*	Machine Scrap	Foundry Scrap
Total Carbon	3.9	3.6	3.25	3.25
Silicon	3.25	1.75	2.5	2.25
Manganese	1.00	1.50	0.5	0.75
Sulphur	0.07	0.04	0.10	0.15
Phosphorus	1.25	0.75	1.00	1.10

culating cupola melting losses. Large pieces of metal are hand picked from the cupola dump and whether the adoption of a system of crushing and magnetic separation is justified on economical grounds depends entirely on the particular circumstances.

Changes in chemical composition previously mentioned are taken into consideration in calculating the final composition of iron from any given mixture. Method of calculation adopted generally is based on simple arithmetical proportion as set out in the following examples. Assuming that the chemical composition of the materials available are as shown in Table XXVII.

A mixture of 2000 pounds total might be assumed to be composed of 400 pounds *A*, 600 pounds *B* and 500 pounds each variety of scrap. Final composition is obtained by multiplying the percentage of each constituent in each component by its proportionate weight and dividing the total obtained by the total weight of the charge. This value with the allowances for melting losses represent the calculated composition of the mixture appears in Table XXVIII.

The final composition is calculated as it appears in Table XXIX.

Method generally adopted in foundries for obtaining a mixture of any desired composition and with suitable materials available is one of inspection and trial based upon the method illustrated. For example, suppose the calculated manganese content

is too high for the particular purpose required. This can be remedied by decreasing the proportions of *A* and *B*. Actual extent is determined by trial and inspection. Several systematic methods of graphically calculating cupola mixtures by utilizing alignment charts or calculators have been proposed. They have

Table XXVIII

METHOD FOR CALCULATING CHARGE

Proposed Mixture Pounds	Total Carbon	Silicon	Manganese	Sulphur	Phosphorus
A—400	15.6	13.0	4.0	0.28	5.0
B—600	21.6	10.5	9.0	0.24	4.5
MS—500	16.25	12.5	2.5	0.50	5.0
FS—500	16.25	11.25	3.75	0.75	5.5
Total 2000	69.7	47.25	19.25	1.77	20.0
Percentage	3.48	2.36	0.96	0.088	1.0

been described in various technical journals, and can be used satisfactorily where the practice is well established.

While melting different mixtures of iron in the same cupola during the same run effective separation of the different mixtures is a factor of considerable importance. The problem can be dealt with in three ways. In the first method the special mixture is charged first, followed by the ordinary or standard mixture. In the second method the special mixture may be charged at any predetermined time during the heat. Separation of this mixture from the other charges generally is affected by a thicker charge of coke, usually double the normal amount. In the third method the special mixture is charged after all the metal belonging to the prior charges has been melted. The bed coke must be charged up to the correct level before placing the new metal charges.

With the exception of the third method the special mixtures are preceded or followed by metal of a different composition and the effectiveness of separation is a subject often discussed among foundrymen. Consensus of opinion favors the view that even with an increased thickness of separating coke, effective separation is not obtained. To prevent any troubles arising from this cause, several charges, neutral or transition charges, are taken from the cupola while changing over from one mixture to the other and used in pouring comparatively unimportant castings.

The question therefore resolves itself into how many transition charges must be allowed before one can be certain of obtaining the special mixtures uncontaminated. Successive charges are not melted separately. Melting proceeds in several charges simultaneously owing to the shape of the melting zone. This tendency is greater in large than in small cupolas, and therefore additional transition charges are necessary. However, two transition charges usually are sufficient to insure effective separation. The third charge of the special mixture may be anticipated with certainty as of the desired composition.

Table XXIX

CHANGE IN COMPOSITION

	Per Cent	Per Cent	Loss or Gain Per Cent
Total Carbon	3.48	3.48	
Silicon	2.36	2.16	—10
Manganese	0.96	0.83	—15
Sulphur	0.088	0.13	+50
Phosphorus	1.0	1.10	+ 0.1

Moldenke has recorded certain interesting experiments in which charges containing varying quantities of nickel and chromium bearing pig iron were melted. The first charge in any of these experiments contained no additions of nickel-chromium pig iron, yet analysis of the first metal tapped revealed the presence of these two elements in substantial amounts, plainly demonstrating the intermingling of successive charges.

That melting does take place well up in the cupola stack and around the circumference of the charge is a well observed fact. Out of a large number of conditions bearing on this point probably the most important is the character of the material charged, volume of pieces and their composition. For example, thin stove plate scrap often can be observed melting among larger pieces of pig iron at the edge of the charge in the neighborhood of the charging door.

Steel scrap which probably melts slower than the remaining cast iron portion of the charge should be charged first with the lightest section and easiest melted material last. Endeavor to

obtain the highest degree of uniformity in size of the materials charged is to be highly recommended. The use of pigs in quarters and a little extra breaking of the scrap will well repay the extra cost in increased uniformity and quality of the resulting metal.

Where the mixtures are made up from materials differing widely in composition and character and particularly in cases where the metal is tapped in small quantities, successive taps may vary widely in composition. This is shown in the following analyses of metal from two taps:

	No. 1 per cent	No. 2 per cent
Total carbon	3.18	3.54
Graphite	2.59	2.83
Combined carbon	0.59	0.71
Silicon	2.98	1.72
Manganese	0.54	0.54
Sulphur	0.06	0.05
Phosphorus	0.46	0.19

The cupola from which this iron was taken was operated 8 hours per day and the 500-pound charges were made up of hematite pig iron, foundry pig iron of a phosphoric nature and scrap. Metal was drawn off at approximately 100 pounds to a tap.

Clearly, the variations from this cause will be less appreciable where several charges are collected in bulk. Of course this is not always convenient. To secure the strictest accuracy the following rules should be observed: Components of the mixtures should approach the final desired composition as nearly as the limits of the melting losses under the particular melting conditions will allow. (2) The components of the mixture should be of guaranteed uniformity of composition in the bulk.

Disposal of cast-iron borings and turnings is one of the continually recurring problems in large engineering establishments. Difference in market price of borings and cast-iron scrap generally is great enough to direct attention of shops associated with foundries to the possibility of utilizing borings and turnings as a portion of the cupola charge. Many attempts have been made to

utilize borings and turnings in this manner. Attempts to charge borings and turnings direct into the cupola have proved impracticable. Principally because the borings jam up the cupola with partially oxidized, partially melted, material, interfere with penetration of the blast and introduce all kinds of irregularities in the character of the molten metal.

Probably the best and most well known method of utilizing borings is that of filling short lengths of pipe with borings and plugging the ends. Canisters of borings thus obtained are introduced directly into the cupola. This method is stated to give good results. An American writer states that when using stove pipe sections containing 50-pound charges the total melting loss does not exceed 2 per cent. This writer also states that the cost of preparing the canisters of borings in this manner did not exceed $2.50 per ton, or 10s per ton at present sterling values.

This method has the advantage of extreme simplicity and avoids the necessity for extensive capital outlay in equipment. However, it is likely to be accompanied by irregular results, and general success as indicated is not an invariable rule. Cause of irregular results obtained can be appreciated when one endeavors to picture the manner in which the container and borings melt. The container arrives at a point in the cupola where it begins to melt, liberating the enclosed borings in a partly loose and partly fused condition. Uncertainty of the complete distribution of these borings in any one charge is responsible for much of the irregularity experienced.

For these reasons attention of foundrymen has been directed to the possibility of forming borings into briquets. Briquetting methods divide themselves into two classes, according to whether or not the borings are subjected to high pressures, and may be classified as follows:

(a) Formation of briquets using chemical binders, with or without moderate pressures.

(b) Formation of briquets by high pressures, with or without the use of chemical binders.

Briquetting methods in the first classification generally appeal to iron founders on account of involving little or no plant ex-

penditure. Cast-iron borings differ from steel borings, where the mutual distortion and entanglement of individual turnings and borings under pressures give sufficient bonding and mechanical strength to the briquet or bale. Even with the application of high pressures, cast-iron boring briquets are liable to show mechanical weakness. For this reason some form of added binder generally is recommended.

A more or less complete list of binders includes tar, pitch and oils, sodium silicate, calcium chloride, sal-ammoniac, portland cement, lime water, clay wash and core gums.

Tar and pitch are dangerous on account of the possibility of a high sulphur content. A similar danger exists with the use of portland cement. Core gums and some of the other binders usually prove too expensive for general commercial purposes.

In practice the clean borings are sprinkled with the requisite quantity of binder in solution or in suspension in water. This is the method followed with sodium silicate, calcium or ammonium chlorides, clay wash and lime water. The sprinkled borings are thoroughly mixed and wetted all over then turned over with a shovel or in a mechanical mixer. Lime, magnesite, cement or other dry powder is intermingled thoroughly with the borings and the chloride solutions or water added subsequently, as in concrete making.

Borings, thoroughly wetted with the binder, are formed into briquets by ramming them in molds of a suitable shape with regular foundry rammers, as in ordinary molding practice.

Briquets also may be formed in a small hand, hydraulic or pneumatically operated press head type of molding machine. The briquets are transferred to a stove for drying and hardening. In the green condition they are weak and require careful handling. Usually they are handled on steel or cast-iron plates, as in ordinary core room practice.

An initial tempering period before final drying and hardening is distinctly advantageous in improving the strength both in the green state and in the dried state. If the wetted briquets are allowed to stand, the temperature rises in accordance with the size, to a point where in many instances steam appears. Sodium

silicate, cement, clay wash and mixtures of lime and calcium chloride are natural bonding materials. Merely as a briquetting and bonding agent sodium silicate probably is the best, and is only objectionable on the ground of cost.

The writer has made extremely hard briquets, using a 10 per cent solution of commercial sodium silicate in water. The rectangular bricks, 4 x 6 x 12 inches, with rounded corners were rammed on a hand-operated, press head, molding machine. They were dried in a core stove, were capable of a considerable amount of rough handling, and withstood perfectly the action of charging into the cupola. A 5 per cent solution gave a weaker briquet, but one that could be handled with sufficient care. Strength of the briquet was improved considerably by allowing an ageing period before drying.

Bonding properties due to the ordinary process of rusting when borings are exposed to the weather, are well known to most foundrymen. Boring piles exposed to weather conditions for a prolonged period, rust together on the exposed portions of the pile, and often develop a hard skin almost impenetrable to a pick-axe.

Superficial oxidation or rusting of the individual borings forms a solid mass of partially-oxidized iron. Probably much of the bond obtained by the use of water solutions, suspensions or mixtures of even natural bonding materials is obtained through the superficial rusting of the borings. Sal-ammoniac and calcium chloride act simply as rusting agents. Their effective action is slow in making a really hard briquet. On this account these bonding materials, accelerators of the natural process of bonding by rusting, involve a considerable amount of handling, also space for stocking and ageing. Effect of tempering or ageing on the strength of briquets before drying undoubtedly is to be ascribed to the rusting action set up by the addition of water. Rise in temperature of the briquets from the oxidation reactions is sufficient evidence of this. In all briquetting processes where wetted borings are used, the strength of the briquets is increased materially by ageing.

Power pressing overcomes the difficulties occasioned by han-

dling the briquets in the green state, and also speeds production. A variety of power presses are available for this purpose. The presses generally are operated hydraulically by rams or by toggle levers operated through direct motor drives or from line shafting. Pressures up to 30 to 40 tons per square inch are utilized on many of these presses. High initial cost of heavy machinery has militated against its more extensive adoption for briquetting cast-iron borings.

A smaller type of briquetting press, 4½ horsepower, has been designed to operate on compressed air of 90 to 100 pounds per square inch pressure or to operate from a direct belt drive. Approximate weight of the whole press is 1½ tons. It is of the knee-joint type with extractor mechanism for ejecting the briquets from the dies. Addition to the borings of 5 per cent slaked lime and 5 per cent water is recommended in using this machine. The resulting briquets are placed on drying trays and allowed to remain for an initial hardening period. They are not dried in an oven. The briquets are allowed to stand for three or four weeks in the open air for final hardening. A sprinkle of water is recommended in dry weather, but too much moisture hardens the skin only, and prevents any further hardening of the inner portions. Well-tempered briquets can stand all kinds of weather and are sufficiently hard for transport. It is stated that presence of slaked lime protects the briquets from excessive rusting due to exposure.

Glenfield & Kennedy, Ltd., Kilmarnock, Scotland, employ a special type of hydraulic press. Three briquet molds may be rotated in turn to a position underneath a hopper and there filled with borings. The filled mold is rotated further and locked in position opposite a hydraulic ram. The second mold then is in position ready to be filled, and by an ingenious arrangement the briquet which can be imagined as existing in mold three, is ejected as a result of pressure applied to mold one. The taper tube molds produce a briquet 3.5 inches diameter at one end, 3.25 inches at the narrow end and with an overall length of 6.5 inches. The taper tube has an initial length of 13.5 inches. Pressure of 35 tons applied to the wide end of the mass of borings reduces the length of the briquet to 6.5 inches.

In this system the borings are mixed with clay wash the consistency of thick cream. Clay content of the final briquet varies from about 5 to 7 per cent. The briquets are allowed to rest for two or three hours for primary hardening. After this initial hardening period they are given a final drying in the core stove for about 13 hours. With care the briquets can be handled in the green condition. When dried they can be dropped onto hard material from a height of 20 feet without disintegration.

A briqueting machine built by the Southwark Foundry & Machine Co., Philadelphia, and installed at the plant of Dodge Bros., Detroit, utilizes mechanical and hydraulic pressure. Power is applied first through a motor and crank and after partial compression mechanically, hydraulic pressure of 20 tons per square inch is applied. Briquets 4 inches diameter, 3 to 4 inches long and weighing 7 pounds each are produced at the rate of 50 tons per 24 hour day.

In the DeGama process, equal pressure is applied on each side of the briquet in a progressive and uniform manner, until a final pressure of approximately 70 tons per square inch is attained. By a shaking arrangement the air bubbles are eliminated completely from the briquet. Some years ago a company started a plant in Cincinnati operating at 50 tons pressure per square inch and producing 5 tons of briquets per hour. A loss of 8 per cent was experienced on remelting an all briquet charge and 4 per cent only on remelting a charge of 80 per cent pig iron and 20 per cent briquets.

All masses of borings contain some fine-grade material and some of coarser grades which, are unevenly distributed in the dry state. Application of liquid binder probably promotes more even distribution of the fine and coarse grades in the mixing operations.

Effect of the relative proportion of fine and coarse grades of borings on the mechanical strength and hardness of the briquet often is ignored. Borings containing a higher proportion of fine grades generally form a stronger and harder briquet. This effect is more pronounced in briquets formed by heavy pressures. Fine grades fill the interstices between the coarser grains and provide a larger contact surface for the bonding

material. In many instances more satisfactory results are obtained subjecting the coarse grades to a preliminary crushing operation. This operation can be carried on conveniently in an ordinary edge runner pan, or mortar mill. Bonding material can be added and thorough mixing assured at the same time.

Utilization of briqueted borings in the cupola mixture still is regarded by many foundrymen with a certain amount of disfavor. This attitude generally accompanies any attempt to utilize materials which have been regarded as waste or scrap. Needless to say this disfavor is unjustifiable. When briquets are used properly, no inferior results follow. Various published experiences on the use of briquets show that the addition of briquets to gray iron mixtures increases the mechanical strength.

Extensive experiments of Fichtner admirably illustrate the influence of remelting various proportions of briquets in the cupola charge. Varying proportions of briquets were added to successive charges of hematite pig and a final charge consisting wholly of briqueted borings also was melted in a cupola. The general conclusion drawn from these experiments was that up to a proportion of 30 per cent briquets in the charge, no great loss was experienced, but the loss steadily increased with increasing proportions of briquets up to 100 per cent. The analytical results graphically are illustrated in the upper-part of Fig. 126. Increase shown in phosphorus and sulphur is due entirely to the composition of the briqueted material. Apart from these constituents the figures show a steady fall in the silicon content with increasing quantities of briquets. The manganese shows little change, and the total carbon falls rapidly with proportions of briquets in excess of 50 per cent.

Silicon loss is confirmed by other investigators. With 25 per cent briquets the silicon was found to drop from 1.96 per cent to 1.63 per cent in certain experiments made in the Sulzer foundries, Switzerland. Under the same conditions, no change in manganese was noted, and the total carbon loss was from 3.00 to 2.75 per cent, a loss of 0.25 per cent.

In melting a charge of 1500 pounds consisting solely of briqueted borings, containing approximately 2 per cent silicon,

Gardiner obtained a white iron indicating an extensive loss in silicon content. A charge of 50 per cent briquets with pig iron and scrap also was found to lose approximately 1 per cent silicon in the process of remelting.

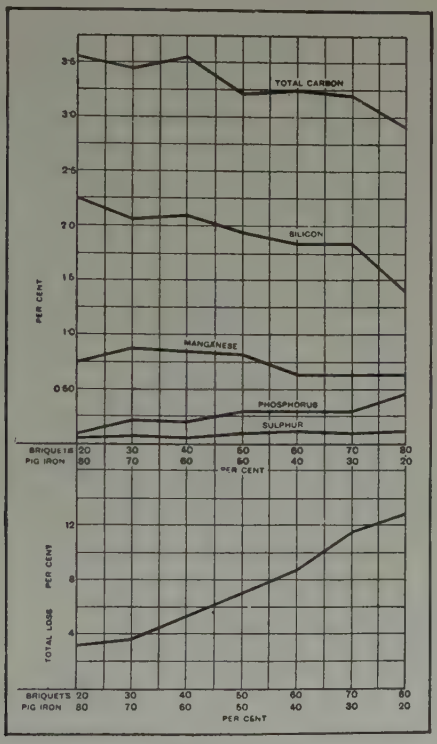


FIG. 126—LOSS AND VARIATION IN CHEMICAL COMPOSITION OF CUPOLA MELTED IRON CONTAINING BRIQUETS

These silicon losses are precisely what would be expected. The briqueted borings were mixed with a wet binder, and were rusted extensively. Silicon loss was brought about by the presence of this rust. The same effect may be observed when melting rusty iron scrap. For this reason, due allowance must be made in calculating the proportions of any mixture containing briquets.

Extent of allowance to be made when using any given

quantity of briquets will depend wholly on the character of the briquets. Where briquets are excessively rusted, the allowance will be greater, and in all cases should be determined by direct experiment. As an approximate guide, a loss of about 0.15 per cent silicon can be expected for every 10 per cent briquets added, in addition to the normal loss due to remelting. Silicon loss shows the necessity for initially higher silicon content in the pig iron or scrap iron proportion of the charge when using briquets, to preserve the same conditions as obtained in the absence of briquets.

Total loss in remelting briquets is of considerable interest in figuring economies arising from their use. In making such estimates, due regard always should be paid to the amount of material added to briquets as binder. Total losses in the experiments of Fichtner, are illustrated graphically in the lower part of Fig. 126. The total loss with 30 per cent briquets in the charge amounted to approximately 4 per cent, and this was found to steadily increase with an increase in the proportion of briquets in the charge. Murphy has recorded a loss of only 2 per cent and Gardiner experienced a loss of 11 per cent.

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